An integrated analysis of sediment geochemistry and flood history of floodplain lakes in the Athabasca Region

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Abstract

This research advances understanding of trace metal deposition in floodplain lakes within the context of the Athabasca oil sands. This thesis begins with an evaluation of geomorphometric changes and flood history in two floodplain lakes of the Athabasca region over the past century. Analyses of historical aerial photographs, weather data, and hydrometric data present a temporal perspective on changes occurring to the floodplain lake environment. These results show that, despite no corresponding climatic shifts or changes to flood frequency, there appears to have been an increase in the area of both Shipyard Lake and Isadore's Lake, though their position with respect to the Athabasca River remains unchanged.

Building on the exploration of floodplain lake geomorphometry, this thesis then presents an analysis of metals in three lakes in the Athabasca region as related to the early development and continuing expansion of the nearby oil sands mining operations. Physical and chemical characteristics of sediment cores, and the concentration of environmentally relevant metals, linked to the timing of development of oil sands mining operations by Pb-210 dating, present an evaluation of temporal changes in the sediment of lake NE20. Due to dynamic depositional environments in Isadore's Lake and Shipyard Lake, no accurate age model could be constructed. Results show that, despite an initial increase in the normalized metal concentrations of As, Ni, and V in each of the lakes following the onset of oil sands mining operations, there appears to be no recent enrichment of trace metals corresponding to the continuing expansion of operations. Results also indicate that disturbances to sedimentation in floodplain lakes, most likely associated with flooding, are an important factor affecting changes in metal deposition.

Overall, this research contributes to the following aspects of our understanding of trace metal content in lake sediments of the Athabasca Region by: i) elucidating trends in sediment quality within floodplain lakes adjacent to oil sands mining operations; ii) investigating methods of normalizing different fractions of metal concentration data to increase understanding of metal transportation and deposition; and iii) assessing the effect disturbances to sedimentation can have on the concentration of metals in lake environments.

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List of Abbreviations

AEP	Alberta Environment & Parks
ANOVA	Analysis of Variance
ATS	Alberta Township System
CCME	Canadian Council of Ministers of the Environment
CF:CS	Constant Flux: Constant Sedimentation
CGVD	Canadian Geodetic Vertical Datum
CIC	Constant Initial Concentration
CNRL	Canadian Natural Resources Limited
CRS	Constant Rate of Supply
CSRS	Canadian Spatial Reference System
CWQG	Canadian Water Quality Guideline
DOC	Dissolved Organic Carbon
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
GCOS	Great Canadian Oil Sands
GIS	Geographic Information Systems
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
ISQG	Interim Sediment Quality Guidelines
JOSM	Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring
LIA	Little Ice-Age
MCL	Maximum Contaminant Level
MDEPQ	Ministère du Développement durable, de l'Environnement et des Parcs, Québec
NRBS	Northern River Basins Study
NREI	Northern River Ecosystems Initiative
PAD	Peace-Athabasca Delta
PAH	Polycyclic Aromatic Hydrocarbons
PCA	Principal Component Analysis
PEL	Probable Effect Level
PEARL	Paleoecological Environmental Assessment and Research Lab
PSA	Particle Size Analyzer

RAMP	Regional Aquatics Monitoring Program
SAGD	Steam Assisted Gravity Drainage
SDWA	Safe Drinking Water Act
TEL	Threshold Effect Level
TDI	Tolerable Daily Intake
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
TRV	Toxicity Reference Value
TSS	Total Suspended Solids
WHO	World Health Organization
WQI	Water Quality Index

1. Introduction

1.1 Research purpose & objectives

Determining the possible impact of large-scale industrial development on the environment requires a broad understanding of the pathways that metals as indicators of human activity may take, of the spatial characteristics of the site, as well as of the background conditions of that site. Together, these factors facilitate effective evaluation of the impact that nearby industrial development has had on the environment. Over the past several decades, much research has been dedicated to establishing this information in the Athabasca region of Alberta, Canada, in which oil sands mining operations have been performed since the mid-1960s (Gismondi and Davidson, 2016). Among the concerns in this area is the concentration of metals in lakes derived through the extraction of bitumen resources. The concentration of metals in lakes close to oil sands mining is a contentious topic among scholars and policy-makers alike.

The purpose of this research is to advance understanding of metal accumulation in floodplain lakes adjacent to the Athabasca River. The long-term accumulation of metal indicators in floodplain lakes represents a considerable gap in the current understanding of metal concentration within the Athabasca region. Wiklund et al. (2014) and others have suggested that there is a dearth of research concerning pre-disturbance sediments in lakes proximal to both the oil sands mining operations and the Athabasca River. The release of metals into the environment through the development of the oil sands has led to concerns as to possible effects on flora and fauna of nearby rivers and lakes (Lacaze et al., 2014; Laird et al., 2013). An analysis of lakes close to oil sands mining operations has demonstrated that, although metal input in the early years of oil sands mining was high, levels have returned to background (Cooke et al., 2017), though the majority of lakes sampled were distant from the floodplain. On the other hand, it has been found that downstream from the source, the concentration of metals is not high enough to induce negative effects (Evans et al., 2016; Kelly et al., 2009; Shotyk et al., 2017; Shotyk et al., 2014), though this has been challenged by others, such as Hodson (2013), due to perceived inadequacy of monitoring programs such as the Regional Aquatics Monitoring Program (RAMP) (Donahue, 2011).

In response to the perceived gaps in our understanding of metals as indicators of human activity in floodplain lakes in the Athabasca region, the present research investigates trends in metal concentrations in floodplain lake sediment close to oil sands mining operations over the past century. The objectives of this research are:

1. To estimate the frequency of flooding in Shipyard and Isadore's Lake, and determine if changes in lake morphometry have occurred. Open-water flooding is expected to exert an influence on the accumulation of metals in these floodplain lakes, so it is important that flood frequency and lake morphometry are considered when investigating metal accumulation. It is hypothesized that the floodplain lakes will experience frequent open-water flooding and will have shifted position, similar to what has been observed in the Athabasca delta lakes.
2. To compare trace metal concentrations in pre-oil sands development sediment with concentrations in post-oil sands development sediment for two floodplain lakes, Shipyard and Isadore's, to determine trends in trace metal concentrations, and compare these trends to trends determined in a lake in the upland region of the Athabasca River, NE20. It is hypothesized that pre- and post-development sediment can be distinguished based on the difference in concentrations of metals released during oil sands processing, and that the upland lake NE20 will be clearly distinguishable from the lower elevation Isadore's Lake and Shipyard Lake based on the concentrations of metals, which is reflective of the different environments and deposition pathways between them. Floodplain lakes may be susceptible to strong erosional and depositional events which will affect dating and the accumulation of metals. Floodplain lakes in the Athabasca regions are important ecological sites that have been insufficiently investigated with regards to their susceptibility to metal accumulation.

Following this introduction will be a literature review exploring the history of oil sands development, existing research on the bitumen and metals, floodplains and their features, and environmental guidelines for sediment. The initial analysis will focus on changes that have occurred to the area and outline of Shipyard Lake and Isadore's Lake, which are two floodplain lakes located adjacent to the Athabasca River and close to oil sands developments. This will be followed by an exploration of changes in trace metal deposition in Shipyard Lake, Isadore's Lake, and NE20, which is a lake located further away from the Athabasca River but still close to oil sands development. The thesis will conclude with a synthesis of these results, focusing on how development of the oil sands over the past half-century have resulted in chemical and physical changes to floodplain lakes in the Athabasca region.

1.2 Geomorphology of floodplain lakes

While previous research in the Athabasca region has focused on the Athabasca River delta, floodplain lakes are also important, as they serve as miniature versions of the highly productive delta lakes. Floodplain lakes are regularly inundated during high flow periods and export accumulated carbon from previous season's growth during flushing and summer rainfall events. Shallow floodplain lakes represent an important ecological niche, particularly for freshwater species of fish, which make use of them for spawning grounds (King et al., 2003). A healthy, biologically productive floodplain lake will support a broad range of species that rely upon them for seasonal nutrition. Since primary productivity within a floodplain lake is controlled by nutrient supply which, in turn, is driven by lake connectivity and mixing, depth and water level play an important role in the productivity of floodplain lakes through its influence on the nutrient availability in the epilimnion (Fee, 1979; Wiklund et al., 2012a). Depth and water level, through this series of interactions, influence the assemblage of biota that may be found in a given lake (Miranda, 2011).

The effect of human development on the morphometry of water bodies must be accounted for when determining the net effect on the local ecology. Anthropogenic effects on water body morphometry include changes due to both climate change, as well as direct local impacts such as damming, dredging, and road construction (De Leeuw et al., 2010). Among the changes that can occur to lakes proximal to heavy industry are decreases in area (Du et al., 2011), increasing sedimentation rate associated with land clearing (Wren et al., 2008), and changes in the water level (Yuan et al., 2015) and thermocline depth (Pérez-Fuentetaja et al., 1999). Increases in lake water level in the Athabasca delta, particularly, have been observed over the past century (Lieffers, 1984). On the other hand, models of climate change impacts to perched basins in the Mackenzie River delta, which is downstream of and fed in part by the Athabasca River delta, predict rapid disappearance of lakes due to reduced flooding input (Marsh and Lesack, 1996).

Prior to flow regulation of the Peace River by the W.A.C. Bennett Dam, lakes in the Peace-Athabasca delta (PAD) north of the study area demonstrated significant seasonal differences in water level (Prowse and Conly, 1998). The influence of this regulation has been mitigated by regulating the release of water from the lake system (Peace-Athabasca Delta Project Group, 1973). This regulation increases seasonal variation, and high spring and summer water levels along with lower fall and winter levels are still observed, though variation in water level is not as great as in the past. This difference in lake water levels is driven by increased flow from snow melt in the spring, and from flooding due to ice jams formed during breakup of river ice. Unlike ice jam floods, flooding from high water levels during open water periods does little to restore the more elevated basins, as open water flooding usually does not reach the water level required to flood the lakes (Peters and Prowse, 2006; Prowse and Lalonde, 1996). Similar ice jam floods occur in the more southerly portions of the Athabasca river, near the oil sands development, and are a major contributing factor to floodplain lake recharge in spring (Hutchison and Hicks, 2007; She et al., 2009). Shipyard Lake is periodically flooded during the open water period and thus should be considered low-closure, whereas Isadore’s Lake is unlikely to experience flooding except under ice-jam conditions and should be considered high-closure (Golder Associates Ltd., 1996; Inc., 2005; Marsh and Hey, 1989). Other hydrological changes that are known to have occurred include the formation of anabranches of the Athabasca River, such as the Embarras River, which formed through the avulsion of river segments during the past century (Timoney and Lee, 2016).

Figure 1.1 Locations of Isadore's Lake, Shipyard Lake, NE20, and Kearl Lake. Derived from Google Earth via Landsat/Copernicus.

The surface area and shape of Shipyard and Isadore's Lakes have been captured in aerial photographs taken as early as 1931. Changes in lake area and shape shown in these images have not been previously analysed. There is a need for further investigation of the geomorphic history of floodplain lakes proximal to the oil sands development area. As a first step in examining temporal trends using sediment cores, the shape and area of the lakes must be investigated.

1.3 Sediment chemistry of floodplain lakes

Early studies of oil sands impact on the Athabasca watershed focused on emissions from development sites. These studies found elevated concentrations of metals in lichens in close proximity to the development, with concentrations decreasing as distance from development increased (Addison and Puckett, 1980). Later researchers demonstrated substantial deposition of PAHs and metals on snow within 50 km of Fort McMurray with concentrations declining rapidly with increasing distance (Kelly et al., 2009; Kirk et al., 2014). Other studies determined that the deposition of metals on sphagnum mosses in the Athabasca region has declined greatly over the past half-century (Shotyk et al., 2017; Shotyk et al., 2014) with similar findings based on sediment core studies of upland lakes, i.e., increased V and Pb loadings during the early oil sands development, which decreased with improvements in technology (Cooke et al., 2017). Other sediment core studies of PAHs in upland lakes demonstrated significant increases in PAH concentrations and fluxes since the onset of bitumen resource development, particularly close to the developments, with little evidence of decline (Kurek et al., 2013).

While sediment core studies have been comprehensive in their analysis of metal (and PAH) distributions in the oil sands areas, they overlooked a key component of the Athabasca River ecosystem, i.e., floodplain lakes, particularly Isadore's Lake and Shipyard Lake which have been monitored by RAMP since 1997 and are located nearby the developments (Hatfield Consultants et al., 2016a). PAH concentrations in surface sediments in both lakes show evidence of increase from 1991 to 2015 and with greater PAHs concentrations than in Kearl Lake, which is located on the upland and also monitored under RAMP (Evans et al., 2016). Trends in sediment metal concentrations were not reported as part of RAMP investigations. Arsenic concentrations in both lakes, however, exceeded Canadian Council of Ministers of the Environment (CCME) guidelines on occasion (CCME, 1995; Hatfield Consultants et al., 2016a). Sediment core studies have not been conducted on either of Isadore's Lake and Shipyard Lake, and their long-term record of metal and PAH deposition is unknown in contrast to upland lakes (Cooke et al., 2017; Kurek et al., 2013; Wiklund et al., 2014). As floodplain lakes are highly productive, and serve as an important ecosystem for fish spawning, impacts from the developments on these lakes should not go unexplored (King et al., 2003).

Since Shipyard and Isadore's Lakes are located within 5 km of intense oil sands activities, it is reasonable to hypothesize that they have been even more profoundly impacted by the developing industry than previously investigated lakes further from development. Metal input to Isadore's Lake and Shipyard Lake may occur through the atmospheric deposition of particulates, runoff from the landscape, periodic flooding by the Athabasca River, streamflow, and groundwater input. On the other hand, wind channeling along the Athabasca River valley may reduce atmospheric deposition of particulates into these lakes. In that case, the primary source of metals may be periodic flooding of these lakes from the Athabasca River. Flooding may also flush out previously deposited metals from these lakes, transporting them further downstream and ultimately to the Athabasca River delta (Wiklund et al., 2014; Wiklund et al., 2012c). While metals are monitored in the Athabasca River water as part of various water quality monitoring programs, these studies have been short term and variations in flow and suspended sediment concentration make it challenging to detect spatial and temporal trends. Flood plain lakes represent interesting sites at which to study the deposition of metals derived from oil sands development, investigating both accumulation of metals in, as well as the loss of metals from the flood plain to the river.

The lake sediment chapter builds on the previous chapter on floodplain lake geomorphology to examine time trends in metals in Shipyard Lake and Isadore's Lake, floodplain lakes located nearby oil sands development, and consider how river hydrology affects these trends. Shipyard Lake is located close to the Syncrude and Suncor development complex which began operation over the late 1960s to early 1970s (Oil Sands Discovery Center, 2016) whereas Isadore's Lake is located further north and in close proximity to the Shell Albian development complex in the watersheds of the Muskeg and Jackpine rivers and the Canadian Natural Resources Horizon complex in the Tar River watershed which began operations in the late 1990s and early 2000s (Oil Sands Discovery Center, 2016). Moreover, this chapter considers lake NE20, an upland lake close to the both development complexes where sediment core studies were conducted with a focus on PAHs (Kurek et al., 2013) and, more recently, metals (Cooke et al., 2017). NE20 is approximately the same distance from development sites as Shipyard and Isadore's, and because it receives atmospheric but not Athabasca River inputs, it can serve as a reference site. Comparisons between these lakes as a function of their response to flooding will be important to understanding the input of metals to lakes of similar proximity to metal sources, but of differing river connectivity and flood frequency.

2. Literature review

2.1 Oil sands development history

Following the first European record of the oil sands in 1778 by Peter Pond, the oil sands were largely believed to hold limited economic value due to the difficulties in separating bitumen from the sand (Hein, 2000). It was not until 1924, when Karl Clark began development of his hot water flotation procedure, that the resource could be exploited (Pasternack and Clark, 1951). A relatively rapid period of development followed: the opening of the Abasand experimental oil sands plant in 1936, and a heavy oil refinery constructed near Lloydminster in 1937. Development stagnated throughout the 1940s, but with the founding of the Great Canadian Oil Sands Project (GCOS) in 1953, the oil sands industry began a half-century of exponential expansion. Since then, production has expanded tremendously, with 2.5 million barrels produced per day in 2016 (Alberta Energy Regulator, 2017).

While it had been founded in 1953, the GCOS company had continuously failed to profit from oil sands mining until, in 1964, it was acquired by the Sun Oil Company. Following this acquisition, the Suncor plant was constructed, which began operation in 1967 (Gismondi and Davidson, 2016). Since then, oil sands mining operations have expanded at a tremendous rate (Nikiforuk, 1997). Until the 1990s oil sands mining was performed with bucket wheel excavators: immense, complex machines which regularly broke down in the cold Canadian climate. This hampered production dramatically, crippling the plant to roughly half of its capacity (Barnes, 2014). This changed in the early 1990s with the introduction of high-capacity trucks and shovels, which effectively spread out the possibility of breakdown over a large fleet, and allowed operators to target the highest-grade of bitumen for processing (Oil Sands Discovery Center, 2016). Production at the Suncor plant has only increased from that point, with reliable technology aiding in the extraction of ever-increasing quantities of bitumen.

The other major oil sands plant in the Athabasca region is Syncrude, a joint venture between Suncor and other oil companies, which began production in 1978 (Oil Sands Discovery Center, 2016). Unlike Suncor, which upgrades their bitumen in an on-site facility, the majority of Syncrude bitumen comes from roughly 30 km away at their Aurora operation, transported in pipelines which facilitate the pre-processing of the bitumen through the application of mechanical energy. This innovation improves processing efficiency and increases profitability of the Syncrude plant.

Due to concerns over the potential environmental impact of such industrial development, industry funded monitoring programs such as the Regional Aquatics Monitoring Program (RAMP) were conducted (Hatfield Consultants et al., 2016a). These efforts have focussed primarily on the main stem and tributaries of the Athabasca River, both of which are highly dynamic environments, with limited monitoring conducted on small lakes and wetlands of the Athabasca River floodplain. Sediment coring studies have been conducted by various researchers examining lakes in the upland region of the Athabasca river valley. These studies have provided a precise and high-resolution chronology. Sediment coring studies in the Athabasca River floodplain and delta have focussed on small lakes more than 200 km downstream of the developments in the Peace-Athabasca delta and long timescales (Hall et al., 2012; Wiklund et al., 2012b; Wiklund et al., 2014). These lakes are subjected to periodic flooding and thus sediment cores sampled from them do not provide as clear a sediment record as those of upland lakes.

2.2 Bitumen and metals in sediment

2.2.1 Bitumen overview

Bitumen refers to a viscous, highly dense form of petroleum, commonly associated with oil sands. Due to the physical characteristics of bitumen, its extraction requires mining practices unique from those used for conventional light and even heavy oils, such as Steam-Assisted Gravity Drainage (SAGD) (Butler, 1994). This is in addition to the need to separate the bitumen from the sand, using processes based upon the Clark Hot Water Extraction Process (Clark, 1929; Masliyah et al., 2004). At the time of extraction, it is unfit for use in oil refineries, and must undergo a process known as upgrading to become suitable for refinement (Abdel-Halim and Subramanian, 2002; Iqbal et al., 2008; Ovalles et al., 1996; Tye and Smith, 2004). These processes effectively reduce the high metal and sulfur contents of bitumen, allowing the new synthetic crude oil to be further refined.

2.2.2 Global bitumen deposits

Deposits of bitumen have been identified in locations such as the United States, Russia, China, and the Congo, with the largest deposits, termed "supergiant", found in the western Canada sedimentary basin of Alberta (McMurray Formation), and the eastern Venezuela basin (Orinoco Belt) (Hein, 2017). These supergiant deposits form in continental multicyclic basins at the point of contact between the continental craton and the up-dip margins of foredeep basins. The McMurray Formation and Orinoco Belt differ, as the former occurs within a non-tectonically active setting, while the latter is found at a site of continent-oceanic plate tectonic collision (Longxin et al., 2009; Martinius et al., 2013; Meyer et al., 2007; Mossop, 1980). In both instances, hydrocarbons migrated up the margin and were trapped. In the case of the McMurray Formation this trap was formed by regional shale seals of the Cretaceous Mannville and Colorado groups, whereas the Orinoco Belt bitumen was trapped by basement uplifts, arches, and fault blocks (Hein, 2017).

2.2.3 Forms of bitumen indicators in Athabasca region

Due to the upgrading requirements for bitumen and heavy oil as compared to conventional crude oil, there is greater potential for the unintended release of chemicals during the production of petroleum products from these resources. Unintended releases of chemicals have been experienced in the Athabasca region, in which there has been observed short-distance transmission of bitumen indicators such as trace metals, PAHs, and nitrates. This transmission has been observed in upland lakes close to the oil sands with the trace metals V and Pb (Cooke et al., 2017), elevated levels of sedimentary PAH content in floodplain lakes along the Athabasca River (Ahad et al., 2015; Evans et al., 2016), and increased atmospheric NO_x and SO_2 content (Hazewinkel et al., 2008; Howell et al., 2014). Metals have been found to enter the atmosphere in windblown dust that can travel significant distances. The presence of Ti and Al has previously been associated with areas of surficial disturbance in the Athabasca River valley (Addison and Puckett, 1980). High concentrations of V (200-250 ppm) have been found broadly distributed throughout the Athabasca River valley, often in association with S, Ti, and, in some instances, Al (Addison and Puckett, 1980). PAHs, as well as NO_x and SO_2, are introduced into the environment through the emissions of bitumen upgraders, and the highest concentrations of these bitumen indicators have been found within 50 km of the major regional upgraders (Howell et al., 2014; Kelly et al., 2009; Kurek et al., 2013).

Vanadium is a strong indicator of the influence of human activity, as it is rare in nature but is enriched in the fly ash of the Suncor bitumen upgrading station (Addison and Puckett, 1980; Barrie, 1980; Davison et al., 1974; Navarro et al., 2007; Vitolo et al., 2001). Addison and Puckett (1980) found V to be strongly enriched in the region surrounding upgrading stations, particularly within 25 km to the south and east of the Suncor upgrading plant. Additionally, vanadium produces toxic effects in mammals, particularly with respect to their reproductive system and development (Domingo, 1996; Llobet and Domingo, 1984).

2.3 Sediment cores as records of metal deposition history

2.3.1 Benefits of sediment cores for investigating metal deposition history

Evaluation of trends in sediment quality can be accomplished by taking samples of surficial sediments, which will provide information as to the present conditions of the sediment. If taken repeatedly over a period of time, as was done at several sites by the Regional Aquatics Monitoring Program (RAMP), the presence of trends in metals can be inferred (Hatfield Consultants et al., 2016a). An alternative means by which to investigate trends in metals is by extracting sediment cores from lakes and rivers that experience regular deposition. These cores may serve as a continuous record of sedimentation, thereby providing information on the rate and timing of metal deposition.

Under ideal conditions, these cores can be accurately dated using methods such as Pb-210 radio-isotopes, allowing comparison to trends in regional economic development or climate conditions. Sediment cores have been used in the Mackenzie delta to document spatial and temporal variation in lake sediment, the response of diatom assemblages to different levels of river connectivity in lakes, and the presence of elevated PAH content in delta lakes from sources unrelated to the Athabasca Oil Sands (Headley et al., 2002; Marsh et al., 1999; Michelutti et al., 2001). In the Peace-Athabasca delta (PAD), sediment cores have been used to determine the long-term flood record of partially-closed oxbow lakes, and the influence of flow regulation and climate variability on local basin hydro-ecology. These studies indicate that, since the onset of oil sands resource development, there has been no discernable increase in PAH concentration in floodplain lakes within the PAD (Hall et al., 2012; Wolfe et al., 2006; Wolfe et al., 2005). These examples demonstrate the effectiveness of sediment cores for investigating a variety of issues in floodplain lake environments.

2.3.2 Dating sediment cores with Pb-210 decay models

Sediment cores are typically dated using the radium decay series (Binford, 1990; Oldfield and Appleby, 1984). This is a sequence of radionuclides that has a known rate of radioactive decay (Chisté et al., 2007). For dating sediment, alpha decay of radionuclides is the relevant decay mode. Alpha decay involves the ejection of an alpha particle (equivalent to an He-4 nucleus) from the nucleus of the parent radionuclide, resulting in a decay series of radionuclides. This decay is accompanied by the emission of 46.5 KeV of gamma radiation, the measurement of which (gamma counting) can be used as a substitute for counting the emission of alpha particles. This known rate of decay and known decay series of radionuclides are the key components of radionuclide dating.

In the radium decay series, Ra-226 on the earth's surface decays into Rn-222 gas by alpha decay and migrates to the atmosphere. With a half-life of 3.8 days, Rn-222 in the atmosphere decays into Pb-210 by primarily alpha decay (though there are intermediate short-lived radionuclides). Natural precipitation and fallout transport this Pb-210 from the atmosphere to the earth's surface, with a distribution that varies based on latitude (Muir et al., 2009). This represents the fraction of unsupported, or excess, Pb-210 in sediment. The supported fraction is represented by the Pb-210 supplied by decay of Rn-222 in sediment that did not migrate to the atmosphere. The activities of parent isotopes Ra-226 and Rn-222 will be in equilibrium with the supported fraction of Pb-210. This supported Pb-210 must be accounted for when calculating dates, as underestimation can strongly impact the age model (Pittauerová et al., 2011).

The activity of unsupported Pb-210 will, under ideal conditions with a constant atmospheric flux of Pb-210 from the atmosphere, form an exponential decay curve when plotted against depth. Since the half-life of Pb-210, based upon the decay rate of Pb-210 (0.031 year^{-1}), is constant (22.3 years), and peak activity will be at the surface under ideal conditions, the decline in unsupported Pb-210 activity with depth in a sediment core can be related to the half-life and dates can be established for the sediment at different depths (Oldfield and Appleby, 1984).

2.3.3 Issues with sediment cores for investigating metal deposition history

Despite the reliability and varied uses of sediment cores, there are issues that may affect their usefulness. A key issue is the remobilization of sediment as a result of flooding or wind action (Bailey and Hamilton, 1997; Carper and Bachmann, 1984; Dunne et al., 1998; Meade, 1994). At flood stage, sediment stored in the floodplain and floodplain lakes may become entrained in the flow and removed from the floodplain, to be replaced by newly-deposited sediment as the flood retreats. This has been observed on the Amazon River in Brazil, for which the sediment budget of the floodplain was found to be well balanced between erosion and supply of sediment (Dunne et al., 1998; Meade, 1994). The observed flooding resulted in the erasure of at least part of the previous year's sedimentation record, which could reduce the value of the sediment core for observing trends in metal deposition. Extreme flooding could additionally lead to erasure of even older sediment, which would create a discontinuous sediment record and negatively impact Pb^{210} dating. Resuspension of sediments within a lake as a result of wind mixing can be problematic, as it will lead to redistribution of sediment and increase spatial heterogeneity (Bailey and Hamilton, 1997; Carper and Bachmann, 1984). Flood-induced spatial heterogeneity reduces reliability of cores as a representation of deposition occurring throughout the lake as metals may become enriched or depleted at different points.

Additionally, since lakes are hydrologically connected to the local groundwater system, there is the possibility of metals mobilizing as a result of redox- and pH-conditions within the lake and leaving the lake through the groundwater system. This has been demonstrated by the mobilization of Cu, Zn, Pb, and Cd in sediments sampled in Hamburg Harbour, in which greatest mobility was observed in oxidized, acidic sediments (Calmano et al., 1993). Groundwater mobilization of metals may lead to an inaccurate assessment of the input of trace metals into floodplain lakes determined from sediment cores. Similar inferences have been drawn from river sediment in the Tyne basin of the United Kingdom, in which fine-scale chemostratigraphy was suggested to provide unreliable data in river systems in which fluctuating chemical and hydrologic conditions are present (Hudson-Edwards et al., 1998). Similar acidification-dominant results have been reported for the sediments of freshwater lakes (Schindler et al., 1980).

2.4 Review of northern Canadian rivers

Rivers described here as northern are those rivers that are within the northern hemisphere and feed into large northern bodies of water, eventually discharging into the Arctic Ocean at above 60º N in latitude. In the context of Canada, the primary northern river is the Mackenzie River which originates in the outflow of Great Slave Lake (Bigras, 1990; Marsh and Lesack, 1996) and whose basin also includes the Peace and Athabasca Rivers. The Slave River is the primary inflow river to Great Slave Lake and originates in the confluence of the Peace and Athabasca Rivers. The Athabasca River enters Lake Athabasca in its southwest corner through the Athabasca delta) and exits a few tens of kilometres to the northwest with its flow combined with lake outflow.

2.4.1 Athabasca River system

The Athabasca River runs 1231 km northeast from the Columbia glacier in southern Alberta, features both meandering and braided sections, and combines with the Peace River to form the Peace-Athabasca delta, which drains into Lake Athabasca (Prowse and Conly, 2002). This river is used as a supply for industrial water for oil sands mining activity, as well as a source of drinking water for northern communities such as Fort Chipewyan. Important tributaries to the Athabasca River include the Clearwater River, Muskeg River, Steepbank River, and Tar River, all of which have been monitored for changes in water quality related to oil sands mining operations (Hatfield Consultants et al., 2016a).

Water quality in the Athabasca River and its tributaries has been the subject of much research throughout recent decades, due to the potential impact of the nearby oil sands mining development. Recent monitoring programs such as RAMP, the Northern River Ecosystems Initiative (NREI), and the Northern River Basins Study (NRBS), have indicated that there are no significant trends in metal concentration in the river (Hatfield Consultants et al., 2016a; Prowse et al., 2006; Prowse and Conly, 2002). The main program for monitoring water quality in and around the development area was RAMP, which initiated monitoring efforts in 1997, and concluded in 2015 to be succeeded by the Joint Canada-Alberta Implementation Plan for Oil Sands Monitoring (JOSM) (Evans et al., 2016; Hatfield Consultants et al., 2016a). Factors that were considered for water quality include the dissolved and total concentration of metals, ions, nutrients, and PAHs.

Water quality in this program was evaluated by comparing sites downstream of, and proximal to, development areas, termed ‘test’ sites, to regional ‘baseline’ sites, located upstream of development. RAMP test sites that were evaluated for water quality were typically found to have a negligible change in water quality as compared to baseline conditions. Exceptions include the lower Steepbank River site, the lower Gregoire River site, and the Hangingstone River site (Hatfield Consultants et al., 2016a). The lower Steepbank River site, in particular, is very close to the center of regional development. Analysis of RAMP data on PAH content of sediment samples taken from the main stem of the Athabasca River, as well as from floodplain lakes and tributary channels, has shown that total PAH content at sites near development has increased relative to background (Evans et al., 2016). Analysis of water and snowpack sampled in 2008, conducted separately from RAMP, found that concentrations of seven metals toxic in high concentrations (Cd, Cu, Pb, Hg, Ni, Ag, and Zn) were greater both around development and downstream of development than they were upstream (Kelly et al., 2010). Other studies have found that metals such as V and Pb, and PAHs such as dibenz(a,h)pyrene have been introduced into the Athabasca River and its floodplain near the oil sands development (Cooke et al., 2017; Kirk et al., 2014; Kurek et al., 2013). Furthermore, the concentration of each of these metals was found to occasionally exceed water quality guidelines for either Canada or Alberta (Canadian Council of Ministers of the Environment, 2007). It must be noted that RAMP has been subjected to significant criticisms throughout its period of activity, primarily attributed to difficulties associated with program design, issues regarding the validity of reference sites, and difficulty validating Environmental Impact Assessment (EIA) predictions (Donahue, 2011; Main, 2011).

2.4.2 The Mackenzie River system

The Mackenzie River basin is the twelfth largest drainage basin in the world, as well as the fourth largest with respect to discharge into the Arctic Ocean. The Mackenzie River is formed by the confluence of the Peace and Athabasca rivers into the Slave River, discharging into Great Slave Lake, which serves as the headwaters of the Mackenzie (Bigras, 1990; Marsh and Lesack, 1996). Large rivers such as the Mackenzie River enhance the productivity of their deltas and estuaries by serving as important sources of nitrogen, phosphorus, and trace metals, but these large rivers are also subject to anthropogenic stressors which can degrade ecosystem health downstream. For the Mackenzie River basin, concerns have focused on chemicals associated with oil sands, although excessive nutrient loading, pulp and paper mill effluent, and other bitumen indicators have also been considered (Hall et al., 2012; Wiklund et al., 2012a). Although many plans have been proposed for the development of hydroelectricity production on the Mackenzie River, none have yet been developed. A number of tributaries to the Mackenzie River, however, have seen the development of hydroelectric dams.

The town of Norman Wells, on the banks of the Mackenzie River in the Northwest Territories, has been intimately involved in the petroleum industry since the early 20th century, hosting both the extraction and refinement of crude oil, as well as pipelines for transporting crude oil to Whitehorse and Zama (Bone and Mahnic, 1984; Nixon and Burgess, 1999). In addition to historical spills that have released large amounts of crude oil into the area between Norman Wells and Whitehorse (Kershaw and Kershaw, 1986), there have been numerous crude oil, wastewater, and chemical spills within the town of Norman Wells centered around petroleum facilities recorded since 1971 (Northwest Territories (Department of Environment & Natural Resources), 2018). Norman Wells oil has been tested for acute toxicity to plankton (Rogerson et al., 1982), juvenile fish (Lockhart et al., 1996), and vegetation (Hutchinson and Freedman, 1978) and has been found to have detrimental effects to each.

Complaints about declining fish quality in the Mackenzie River near Norman Wells spurred investigation into potential impacts from hydrocarbon development in the area, which found levels of aromatic hydrocarbons in local fish consistently elevated above baseline (Lockhart et al., 1987). Analysis of PAHs in the Mackenzie River and smaller rivers in the Mackenzie delta determined that petrogenic PAHs were the primary form of PAHs in the Mackenzie River, the source of which was determined to be the erosion of outcrops of the petroleum-rich Devonian Canol formation (Yunker et al., 2002). Conversely, petrogenic PAHs were essentially absent in the smaller rivers.

Water quality in the Mackenzie River downstream of Norman Wells was evaluated with respect to the CCME Canadian Water Quality Guidelines (CWQGs), which found that overall water quality was considered marginal for drinking and other aquatic uses, though under protocols 2 (excluding physical variables and metals), 6 (considering only major ions), and 7 (considering only nutrients), water quality was rated good to excellent (Lumb et al., 2006). High turbidity was considered to be a main contributing factor in reducing overall water quality, as it was deemed responsible for high metal concentrations.

2.4.3 The Slave River system

Formed at the confluence of the Peace River and the Lake Athabasca-fed Rivière des Rochers, the Slave River runs 434 km northwest before discharging into Great Slave Lake. As with the Athabasca River, it has been subjected to monitoring under the NRBS (Prowse et al., 2002) and NREI (Prowse et al., 2006), which aimed to observe changes occurring to the water quality of the lakes related to industrial development mainly related to pulp mills, and changes to hydrology and flow regulation linked to climate change and upstream flow regulation. While water quality in the Slave River was found to be within CCME guidelines regarding both trace metals and organic compounds, there have been substantial changes observed to the seasonal patterns of flow, particularly with regards to ice cover, as well as morphological changes in the Slave River delta.

Shallow floodplain lakes along the Slave River and within the Slave River delta have been subjected to significant investigation regarding the role of flooding and its influence on their microbiology, morphology, and water chemistry (Sokal et al., 2010; Wrona et al., 2000). Physical characteristics and chemistry of non-flooded and frequently flooded lakes were found to be functionally unchanging between years, while those parameters in infrequently flooded lakes could shift dramatically. Flooding was observed to reduce available nutrients in lakes, and non-flooded lakes were shown to contain more macrophyte biomass. Additionally, flooding was found to introduce short-lived planktonic diatoms to lakes, which were entirely absent in non-flooded lakes (Sokal et al., 2010).

2.5 Floodplains

Floodplains lie between the banks of a river or stream and the base of the valley walls, and represent an important zone for agriculture, human development, and biological productivity. These areas experience flooding as a response to seasonal river flood pulses, direct precipitation, or groundwater input, which determine the material delivered to them (Junk et al., 1989). This periodic inundation creates the morphology of land features found on floodplains and defines the biota that dwell upon them.

2.5.1 Floodplain landforms and features

The landforms and features of a floodplain will typically include: oxbow lakes, formed through the cut-off of dead meanders of the main river channel; point bars, at which deposited river sediment accumulates on the convex side of bends in the river; meander scrolls, river curve features of alternating high and low sections formed by channel migration; sloughs, in which stagnant water accumulates in the depressions of meander sloughs; natural levées, channel-adjacent berms elevated above the average floodplain elevation, adjacent to the channel and typically composed of coarser material; backswamp deposits, composed of fine material not trapped by levées; and sand splays, which represent the deposition of flood debris (Waugh, 2000). Hydrologically, floodplains are host to a perirheic zone, in which river and local water mix (Mertes, 1997).

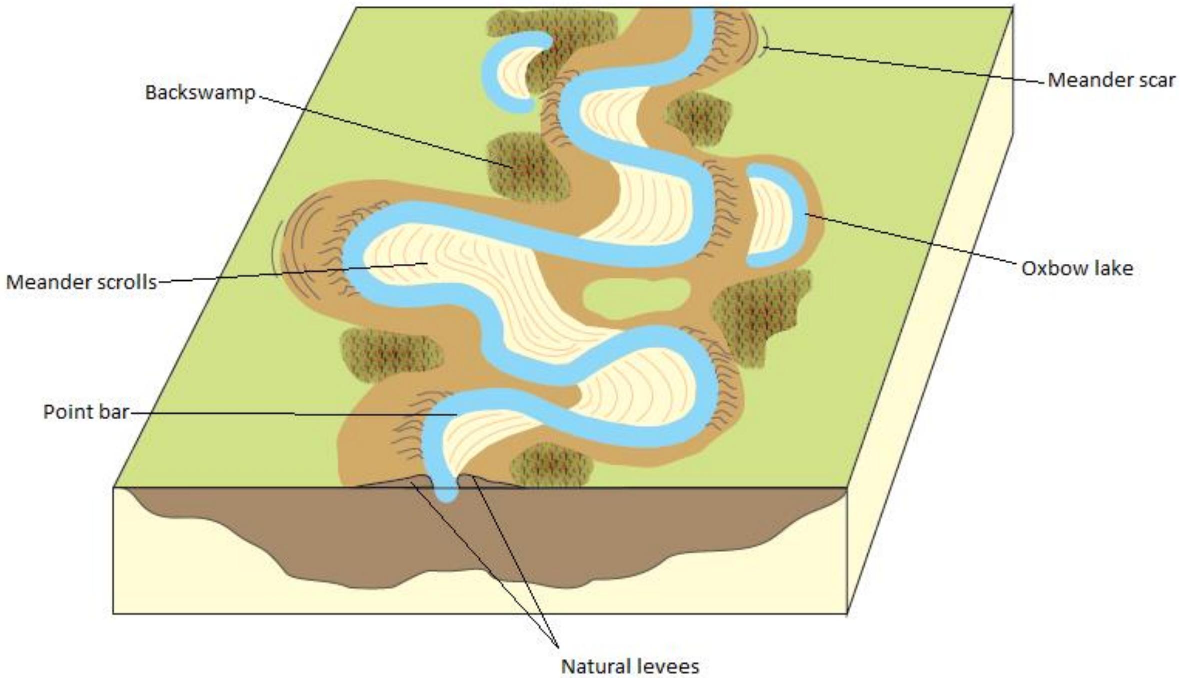


Figure 2.1 Landforms and features of a floodplain of a meandering river after (Holden, 2005).

2.5.2 River floodplain formation & morphology

Current knowledge of floodplain formation contradicts the early view that lateral accretion is always the dominant mechanism for the formation of floodplains (Lewin, 1983). The primary mechanisms by which floodplains develop are: accretion of lateral point bars, in which point bars are built up inwards to their channel by fallout of suspended sediment; vertical accretion by overbank flooding, in which sediment is introduced to floodplains by the rising floodwaters and accretes as the water recedes; and accretion across braid-channels, in which sediment becomes trapped upon sandflats within the channel (Nanson and Croke, 1992). Of importance to the Athabasca floodplain is the additional process of counterpoint accretion, which results from low-angle impingement of channels against erosion resistant material (Hubbard et al., 2011; Smith et al., 2009); Other less common mechanisms are oblique accretion, in which channel migration, associated with a steep convex bank, results in the lateral accumulation of fine-grained sediment (Page et al., 2003); and accretion within abandoned channels, in which, during a gradual cut-off of a previous meander, sediments are deposited as low-flow sedimentary structures prior to the formation of an oxbow lake (Nanson and Croke, 1992; Walker, 1976).

Although terms such as ‘riparian zone’ are misleading in floodplain environments due to their dynamic nature (Nanson and Croke, 1992), it is a useful term when considering the influence of riparian vegetation on the sediment content of floodplain lakes. Riparian retention of sediment exerts a strong control on the particulate matter that enters an adjacent water body, depending primarily on the width of the riparian buffer zone, the slope of the zone, and the nature of vegetation found there (Hook, 2003; Steiger et al., 2003). An analysis of the character of material deposited on the Mississippi floodplain riparian zone following flood events from 1995-1998 demonstrated that sand-sized particles are primarily deposited on natural, vegetated levees, while clay-sized material was primarily deposited within oxbows, wetlands, and the floodplain matrix (Heimann and Roell, 2000). There was no significant difference in silt content between the observed landforms. Additionally, floodplain lakes are typically associated with a state of dynamic equilibrium; that is, due to flood patterns, there is an alternation between periods of disturbance and productivity (Bridge, 2009). This state of dynamic equilibrium, and the effect of riparian retention on nutrient availability (Brunet et al., 1994), is critical in maintaining the biodiversity of the riparian zone, as it benefits both non-interactive (dominated by abiotic factors) and interactive (dominated by organisms of same trophic level exerting pressures on each other) organism communities (Cornell and Lawton, 1992; Ward et al., 1999).

Floodplains are often underlain by deposits of previously abandoned channels, and overlain by finer-grained flood deposits (Bridge, 2009). This sedimentary sequence is due to the lateral migration of channels, which, over time, serve to both erode and aggrade their adjacent floodplain. The strata of floodplain sediments are defined by individual flood events, which can vary between 0.1 cm – 10 cm in thickness (Bridge, 2009). These facies will begin with an erosional surface, representing scour of the floodplain surface prior to deposition of sediment (Perez-Arlucea and Smith, 1999). The specific flood history can be inferred from the pattern of the facies: decelerating flow will be associated with upward-fining strata, while flows that initially accelerate then decelerate will be associated with upward-coarsening followed by fining. The deposition of sediment in floodplains, however, will depend strongly on local flow conditions and the availability of sediment. Sediment size on the floodplain will vary from fine sand to clay, the proportions and spatial distribution of which depending upon proximity to the main channel as well as local vegetation conditions (Bridge, 2009; Perez-Arlucea and Smith, 1999).

2.5.3 Oxbow lakes

A key feature of floodplains, oxbow lakes, form from the cut-off and sealing of previous meanders as bank erosion and flooding create more efficient channels (Figure 2.2) (Charlton, 2008; Southard, 2015). These lakes may be classified based upon their hydrology, morphology, and hydrochemistry. The hydrological classifications are defined by the dominant direction of water circulation between river and lake: evaporation, in which vertical circulation dominates; flooding, in which horizontal circulation dominates; or exchange, in which neither is dominant (Hamilton and Lewis Jr, 1990). Alternative classification methods that incorporate the local hydrological regime and consider groundwater have also been used (Brock et al., 2007).

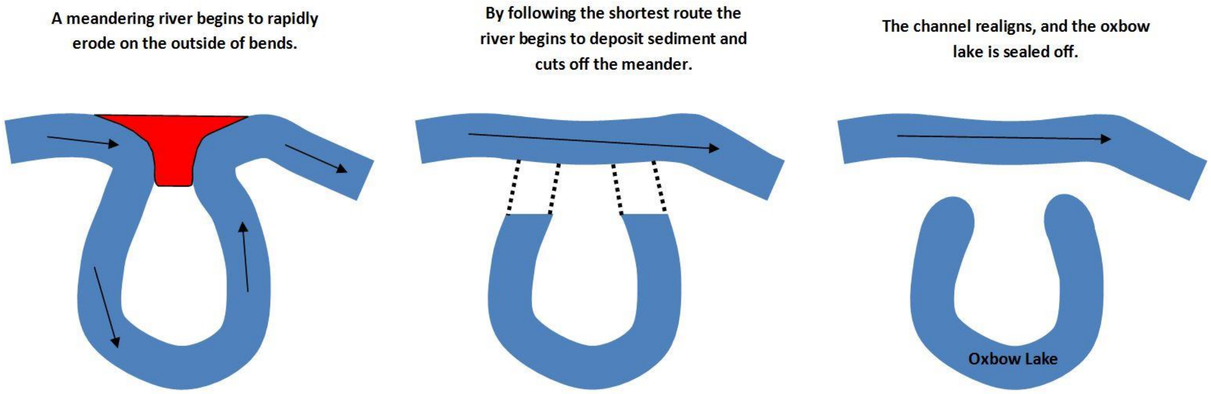


Figure 2.2 Formation of an Oxbow Lake through meander cut-off. Image after (Trenhaile, 1998).

2.5.4 Ice jam flooding

The breakup of ice on northern rivers typically does not result in significant flooding outside of what is expected from the annual nival freshet, but this is not the case during an ice jam flood. Ice jam floods occur throughout Canada, and result from exceptionally long, cold winters, in which the river ice builds thicker, followed by a sudden rise in temperature (Andres and Doyle, 1984; Beltaos, 1995; Hutchison and Hicks, 2007; She et al., 2009). The buildup of ice can increase the effective water level by a large amount, with recorded rises of up to 12 m (Beltaos, 1995). The Athabasca River is characteristic of a north-flowing river with its headwaters to the south, creating a situation in which the spring melt will occur upstream while the river is still frozen downstream, resulting in frequent ice jams (Beltaos et al., 2006b).

2.5.5 Alteration of floodplains

Industrial development has had serious effects on the morphology and ecosystem health of floodplains. These effects on the floodplain are often driven by changes in flow volume, which may result indirectly from climate change, or through the direct manipulation of the upstream drainage network via stream channelization, damming, canal and artificial levee construction, dredging, and other means (De Leeuw et al., 2010; Hupp et al., 2009; Sparks et al., 1990). These alterations have been associated with shifts from dynamic equilibrium, thereby forcing the aggradation or erosion of stable environments. The rapid disappearance of delta lakes has been predicted for the upper Mackenzie delta due to reduced flood input, though this is compounded by the damming of the Peace River and reliance on ice jams for flooding (Marsh and Lesack, 1996).

2.6 Sediment quality guidelines review

Sediment quality in Canada is evaluated against metrics set by the Canadian Council of Ministers of the Environment (CCME) (Canadian Council of Ministers of the Environment, 1995), though there are additional regional guidelines set by provincial governments (Alberta Environment & Sustainable Resource Development, 2014). These metrics outline levels of metals and other substances at which they will be deemed harmful to either aquatic or human life exposed to them. Both the CCME guidelines as well as the Alberta provincial guidelines are based upon Probable-Effect Levels (PELs), which are highly comparable to guidelines set by other governments which also use PEL-based values (Hübner et al., 2009). Other guidelines that use PEL-based values include the Numerical Sediment Quality Assessment Guidelines for Florida Inland Waters (MacDonald et al., 2003), the National Oceanic and Atmospheric Administration 2008 guidelines, and the guidelines set for Quebec, Canada, by Environment Canada and Quebec's

Ministère du Développement durable, de l'Environnement et des Parcs, Québec (MDEPQ) (EC MDEPQ, 2007); conversely, the Environmental Protection Agency (EPA) of the United States makes use of a Toxicity Reference Value (TRV) – based guideline system (Hübner et al., 2009; United States Environmental Protection Agency, 2017). It should be noted that the US EPA guideline is much lower than the PEL-based guidelines, and is similar to, though still lower than, the Threshold-Effect Level (TEL) or Interim Sediment Quality Guideline (ISGQ) values set by the PEL-based guidelines.

3. Study area

The Athabasca region lies within the northeastern-most part of the boreal plains ecozone (Wiken, 1986). This ecozone is characterized by a yearly annual temperature below freezing, flat to gently-rolling terrain, and is heavily forested by primarily coniferous trees such as spruce and fir (Grubb, 1987). Due to ice-jamming in the region's waterways, floods are relatively common during the spring freshet period (Beltaos et al., 2006b), although flooding may become less regular due to both climate change and human development in the region. In summer, water levels in the Athabasca River can change as much as 2 to 4 m over a period of a few hours during strong flow caused by precipitation events (Barton and Wallace, 1979).

This region is underlain by the McMurray Formation, a Cretaceous deposit of sandstone, shale, and bituminous sands of massive economic value. The McMurray Formation is overlain by the marine shale and sandstone of the Clearwater Formation, and is underlain by the shale and limestone of the Waterways Formation. Further overlying the Clearwater Formation is the sandstone of the Grand Rapids Formation, before reaching the surface (Conly et al., 2002; Kleindienst, 2005). Based on their relative proximity to the Athabasca River and their elevations, both Shipyard Lake and Isadore's Lake are likely underlain by the McMurray formation, while the more distant NE20 may be underlain by unconsolidated till, with lenses of outwash sand and gravel (Conly et al., 2002).

3.1 Overview of NE20, Isadore's Lake, and Shipyard Lake features

The major features of Shipyard, Isadore's and NE20 are shown in in Table 3.1. Shipyard Lake and Isadore's Lake, with surface areas of 21.3 ha and 33.7 ha respectively are larger than NE20 at 5 ha. Moreover, Isadore's Lake has a substantially larger watershed than Shipyard with a catchment to lake area ratio of 462.9 versus 65.7; the catchment to lake area ratio for NE20 is 28.4. Shipyard Lake and Isadore's Lake were slightly alkaline with Isadore's having a higher specific conductivity and sulfate concentrations than Shipyard Lake, likely due to saline creek influences. NE20 had very low sulfate concentrations with specific conductivity not measured. All lakes were high in dissolved organic carbon with Isadore's Lake having the lowest average concentration. The lakes were productive with high total phosphorus and nitrogen concentrations and moderately high chlorophyll concentrations. The Athabasca River exhibits a braided channel form adjacent to these lakes.

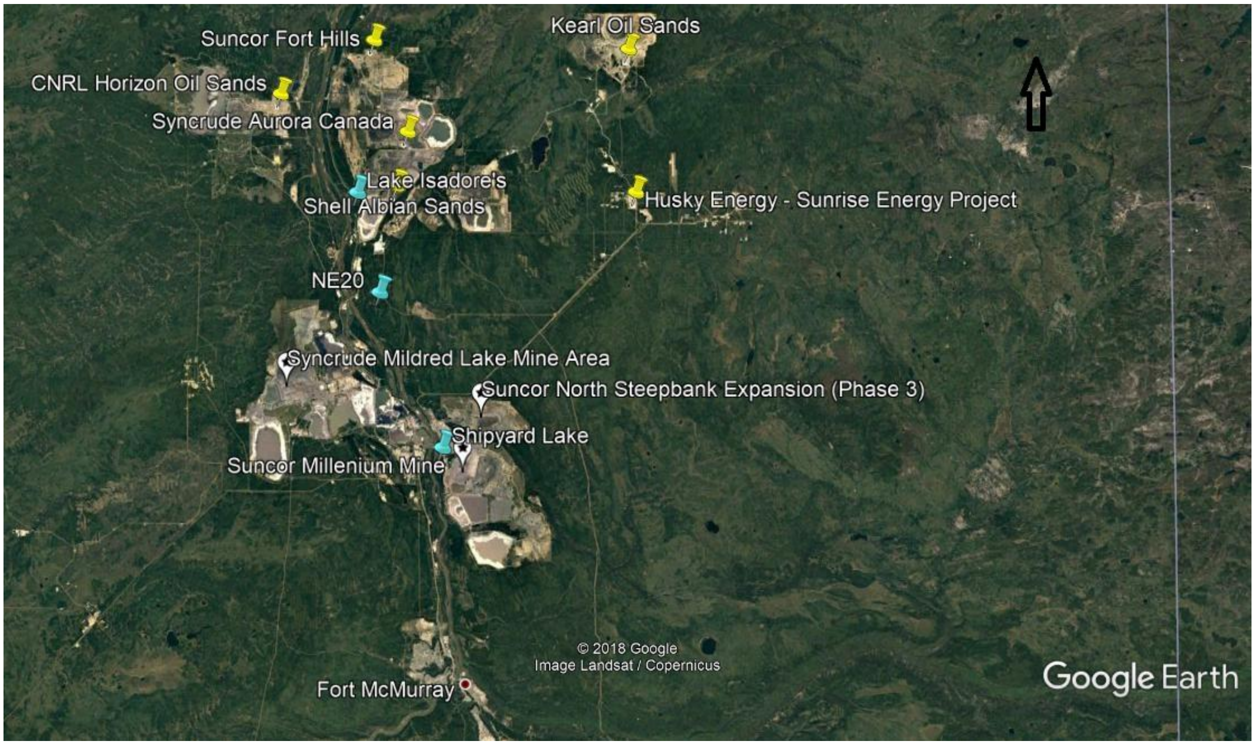


Figure 3.1 Map of Athabasca Oil Sands developments and study lakes. Derived from Google Earth, via Landsat/Copernicus.

Table 3.1 Characteristics of Shipyard, Isadore's, and NE20 lakes.

Lake	**Lake Area (ha.) ***	**Max Depth (m)**	**Catchment Area (ha.)**	**S. cond. (µS/cm) ****	**Sulfate (mg/l) ****	**pH ****	**DOC (mg/l) ****	**TN (µg/l) ****	**TP (µg/L) ****	**Chl a (µg/l) ****	**Total Org. C (%) ****
NE-20 winter	5	4.1	142	-	0.9	7.6	20.6	928	17.3	3.5	28.3
Shipyard Fall	21.3	2.2	1,400	354	7.2	8.2	19.5	982	23.3	1.6	14.3
Isadore’ s Fall	33.7	4.3	15,600	552	139	8.1	11.1	908	40	7.9	6

* Lake area based on 2012 aerial photographs for Isadore's and Shipyard Lake and based on Cooke et al. (2017) and Kurek et al. (2013) for NE20.

** Water chemistry data from RAMP (1999-2016) and Kurek et al. (2013).

*** Total organic carbon data in surface sediments for Shipyard and Isadore’ s Lake are derived from RAMP (1999-2016), and the average content from 0-3 cm of the NE20 core measured in the present study.

3.2 NE20

NE20 lies in an upland area roughly two kilometres east of the Athabasca River, with an average water surface elevation of 267 m a.s.l., 37 m above the level of the water level of the nearby section of the Athabasca River and is not influenced by Athabasca River inputs (Figure 3.2). NE20 has been shown to be heavily influenced by oil sands mining. This is exemplified by PAH concentrations in sediments in NE20 increasing sharply concurrent with oil sands developments (Hrudey, 2013; Kurek et al., 2013). In contrast to the pronounced and continuous increases in PAH coinciding with industry expansion, As and V concentration in NE20 sediments was seen to increase during the early years of the development, but subsequently returned to background levels (Cooke et al., 2017). NE20 will serve as an upland comparison to Isadore's and Shipyard in a region of close proximity to the oil sands developments.

Figure 3.2 NE20 as viewed on Google Earth on September 11, 2016. The March 2016 coring location is shown in blue.

3.3 Isadore's Lake

Isadore's Lake is located approximately 30 km downstream from Shipyard Lake (Figure 1.1, Figure 3.3). Like Shipyard Lake, it is adjacent to the east bank of the Athabasca River. Isadore's Lake lies less than 3 km southwest of the CNRL Muskeg River Mine and less than 2 km west of the Shell Albian Sands tailings pond, which opened in 2002, well after the initial large scale operations in the 1960s and 1970s (Oil Sands Discovery Center, 2016). Isadore's Lake has greater area than Shipyard (37.2 ha vs 21.3), is deeper (4.4 m versus 2.3 m) and has a larger catchment area (15,600 ha versus 1400 ha) (Albian Sands Energy Inc. 2005). Mills Creek on the eastern bank of Isadore's Lake provides the majority of inflowing water to Isadore's Lake. Reports of the Isadore's Lake's area are inconsistent, ranging from 3.7 ha in 1986, to 32.0 ha in 1974 with variations likely related to short-term and long-term climatic variability and beaver dams affecting the water budget of the lake (Hatfield Consultants, 2004). Increases in lake water level following low periods would be expected to result in increased sediment deposition into the deeper regions of the Isadore's Lake. The average depth of Isadore's Lake was reported as 1.45 m (Hatfield Consultants, 2004).

Mean lake level is 233.74 m a.s.l., which is 3.7 m above the average Athabasca River water level adjacent to Isadore's Lake (Albian Sands Energy Inc. 2005). Flooding is therefore likely to be an infrequent and brief occurrence. The 20-year flood level for the Athabasca River is roughly equal to the average lake water level, while the 100-year level surpasses it by 1.2 m, and levels reached during ice jam conditions surpass it by 3 m (Albian Sands Energy Inc. 2005). An example of an ice jam flood on the Athabasca River that could cause Isadore's Lake to flood was observed in 1987, during which a 4.6 m increase in water level was observed at MacEwan Bridge (Hutchison and Hicks, 2007). Isadore's Lake likely receives input from the Athabasca River through seepage and by inflow through its southern end depending on time of year and lake water level (Albian Sands Energy Inc. 2005). The annual groundwater input to Isadore's Lake varies greatly, ranging from 32,000 m^3 to 315,000 m^3 (Albian Sands Energy Inc. 2005). Outflow may be primarily through seepage, since surface outflows through the northern outlet channel were observed to be minor (Albian Sands Energy Inc. 2005). Aquatic vegetation is composed primarily of emergent species, along with low shrubs and ferns on the outer lakeshore.

PAHs such as dibenzothiophene were relatively enriched in Isadore's Lake compared to background levels with atmospheric deposition inferred as a possible source (Dayyani et al., 2016). While ΣPAH concentration of Isadore's Lake showed no trend during the study period of Evans et al. (2016), %alkylated PAHs, C_1-C_4 phenanthrenes/anthracenes, and dibenzothiophenes (ΣDBTs) were found to have increased from 2001 – 2014. Additionally, Hatfield Consultants et al. (2016b) found that F3 (>C16-C34) hydrocarbons had increased in concentration in Isadore's Lake relative to the baseline concentration. Arsenic frequently exceeded CCME sediment quality guidelines while guidelines for PAHs were seldom exceeded (Evans et al., 2016; Hatfield Consultants et al., 2016a). Collectively, these increasing trends and guideline exceedances suggest that Isadore's Lake may be subject to industry influences.

Figure 3.3 Isadore's Lake as viewed on Google Earth via DigitalGlobe on September 5, 2016. The March 2016 coring location is shown in red.

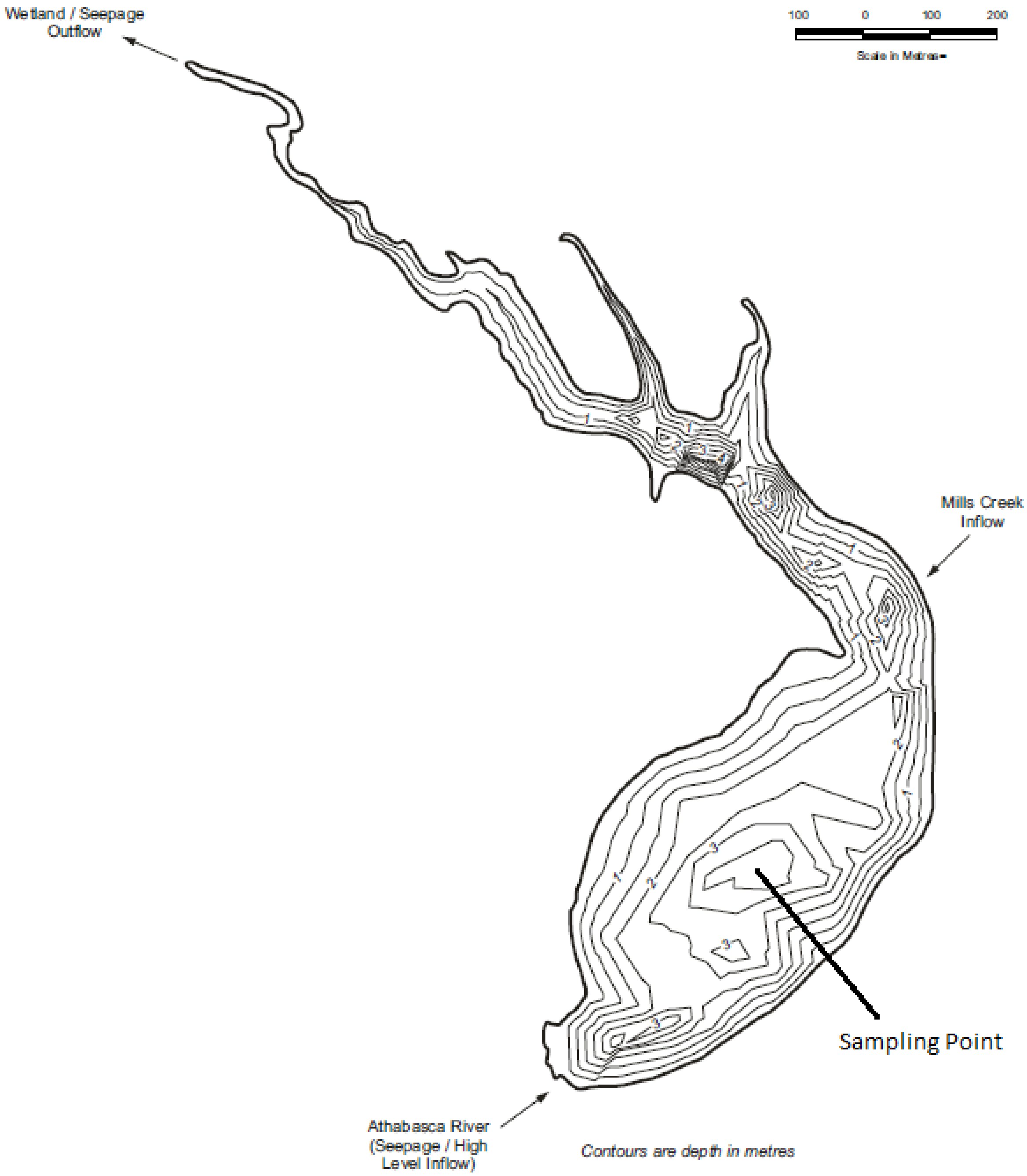


Figure 3.4 Sampling point of Isadore's Lake with respect to its bathymetry, after Albian Sands Energy Inc (2005).

3.4 Shipyard Lake

Shipyard Lake lies east of the Athabasca River, adjacent to the Suncor oil sands mining facility which is located north of the Steepbank River and began operations in 1967 (Figure 3.1, Figure 3.5). The first large scale oil sands mining development, the GCOS project (now Suncor), was constructed immediately northeast of Shipyard Lake in 1967 across the Athabasca River, followed by the subsequent North Steepbank expansion to the north and west of Shipyard Lake beginning in 1997 (Oil Sands Discovery Center, 2016). The lake is relatively large at 21.3 ha, shallow with a reported maximum depth of 2.2 m (Golder Associates Ltd., 1996), and has a catchment area of 1400 ha. The average water level of Shipyard Lake is approximately 237.2 m a.s.l. Canadian Spatial Reference System (CSRS), which is approximately equal to the average water level of the Athabasca River adjacent to Shipyard Lake (Golder Associates Ltd., 1996). Due to its low topography, Shipyard Lake is flooded by the Athabasca River during periods of high summer flow. Flooding occurs every 1-1.7 years. There are two primary creeks (Creek 2 and an unnamed creek) and at least five smaller creeks which provide direct flow into Shipyard Lake, all entering from the east. Both primary creeks have well developed channels and originate in the uplands. The smaller creeks inflow originates from overland or intermittent flow from the uplands. Additionally, a series of beaver dams store water and suspended sediments, regulating flow into Shipyard Lake. Shipyard Lake discharges into the Athabasca River via Shipyard Creek to the north with beaver dams impacting its water level. It is classified as a riparian wetland (Hatfield Consultants et al., 2016a) with abundant and diverse emergent, submergent, and floating vegetation. While most metals in water remained at or near previously measured levels in the water column, there is some increase in sodium and chloride concentration. Concentrations of arsenic and seven PAHs have been found to periodically exceed sediment quality guidelines in Shipyard Lake (CCME, 1995; Evans et al., 2016; Hatfield Consultants et al., 2016a).

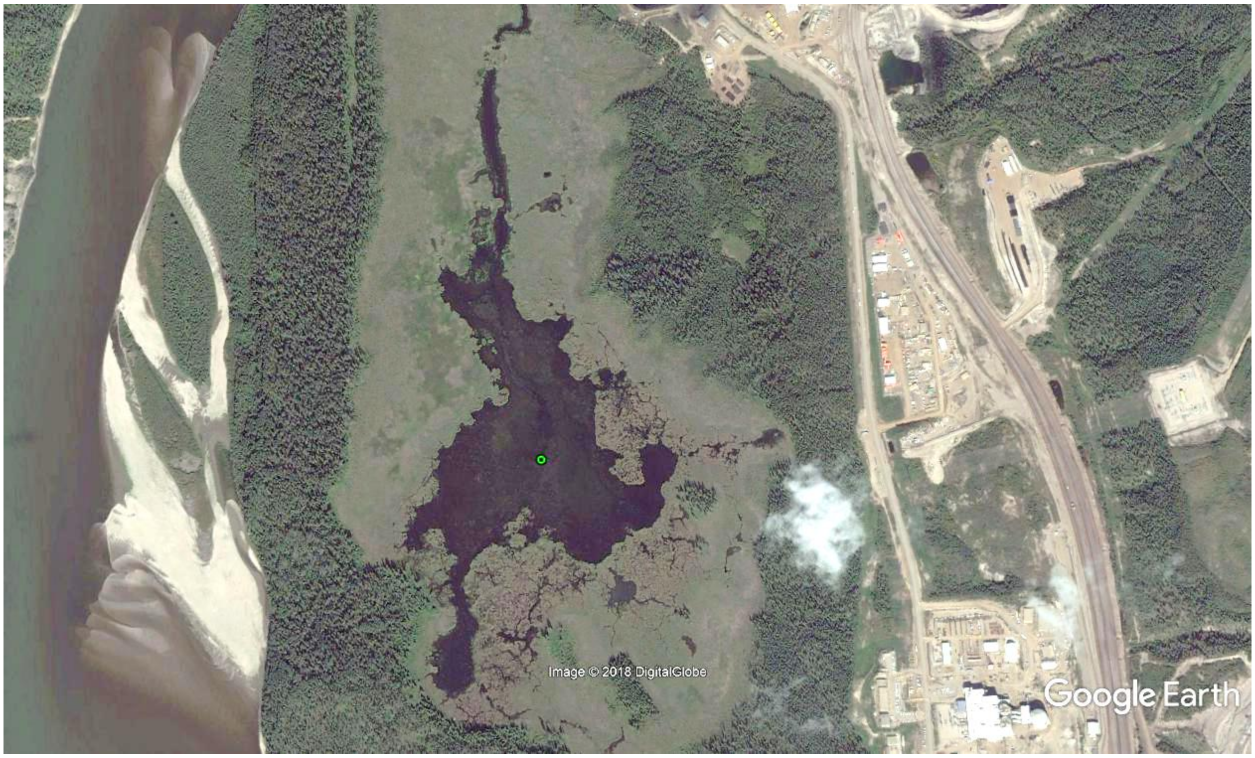


Figure 3.5 Shipyard Lake as viewed on Google Earth via DigitalGlobe on August 8, 2015. The March 2016 coring location is shown in green.

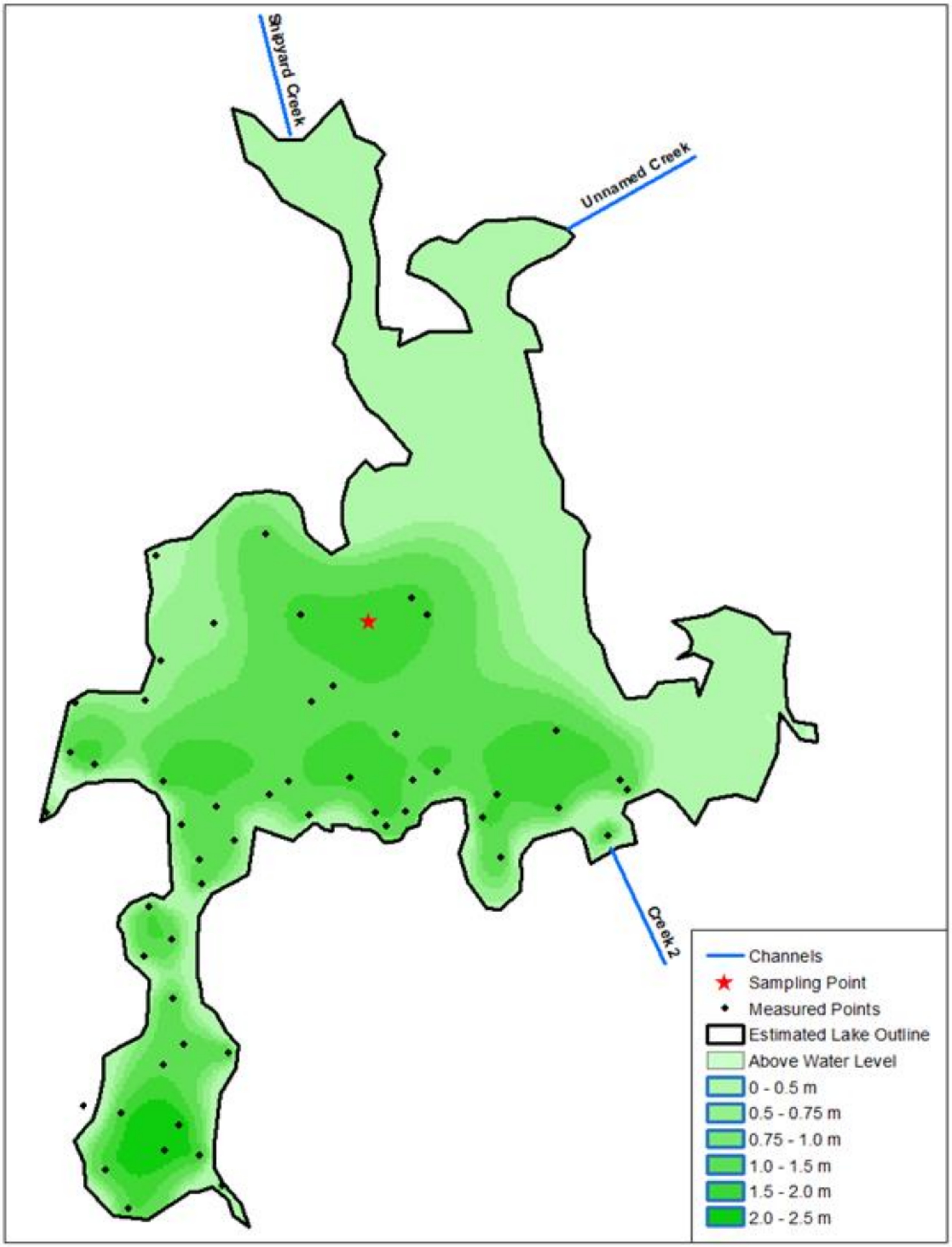


Figure 3.6 Sampling point of Shipyard Lake with respect to its bathymetry, after Golder Associates Ltd. (1996).

4. Methods

4.1 Geomorphology methods

4.1.1 Fort McMurray weather trends

To determine if changes in local weather patterns could have impacted the morphometry of Isadore's Lake and Shipyard Lake, weather data was analysed. Weather data was downloaded from the Canadian government weather archive for station Fort McMurray A, located at 56°39' N, 111°13'W for 1944-2007 (NAVCAN, 2019). Mean annual temperature (˚C, total annual precipitation (mm), total annual snow (mm), and total annual rain (mm) were selected as variables for analysis, which involved linear modelling of those variables against year.

4.1.2 Flood level frequency

Water level data were acquired from HYDAT for station 07DA001 Athabasca River Below Fort McMurray (HYDAT, 2018). As most of the measurements were for discharge only, a rating curve was built from level and discharge measurements taken from 2012 – 2016 (Figure 4.1). Winter data was excluded (November – March) as ice cover is frequent in this region and negatively affects the effectiveness of a rating curve. This curve was used to back-calculate the water level for measurements taken from 1957-2012, providing water levels relative to the bottom of the Athabasca River at the sampling point. These water level values were converted to elevation above sea level relative to the Canadian Geodetic Vertical Datum (CGVD) 2013 by adding them to the elevation of the river bed at the sampling point at 237.5 m a.s.l. Monthly maximum water levels were compared to the estimated minimum elevation required for flooding into Shipyard and/or Isadore's Lake, which were determined from baseline studies of the hydrology of these lakes (Golder Associates Ltd. 1996; Albian Sands Energy Inc. 2005).

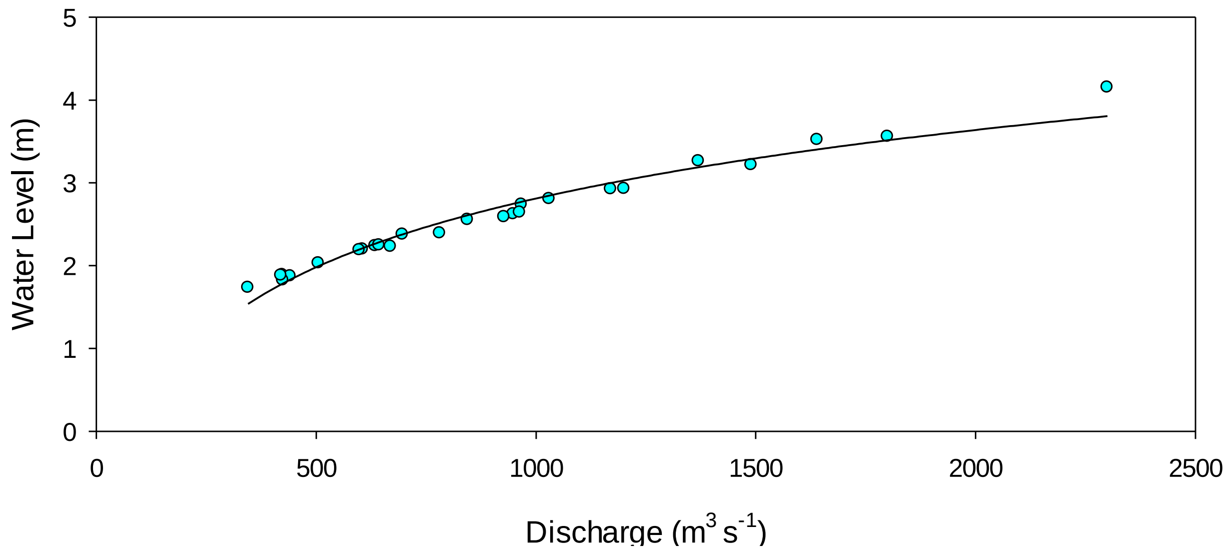


Figure 4.1 Rating curve for station 07DA001 ‘Athabasca River Below Fort McMurray’ (NAVCAN, 2019).

4.1.3 Georeferencing and lake area

Aerial photographs and satellite images were provided by Alberta Environment & Parks (AEP) and the University of Calgary Library. Images of Isadore’s Lake were selected from flight paths with coordinates that crossed Alberta Township System (ATS) 95-10-4, while Shipyard Lake images used ATS 92-09-4. These images were georeferenced against topographic maps provided by NRCAN, for Fort MacMurray zones 74D and 74E. Georeferencing was performed using ArcMap 10.5, and followed standard conventions of determining points on the images that corresponded to those on the map (Price, 2010). This was slightly confounded for images taken prior to 1960, in which there are no human map features present in the images. This was accommodated by accepting relatively fixed natural features as reference points, such as stream mouths.

Outlines of lakes were constructed by tracing polygons around georeferenced lake images. Due to the variety of scales and image quality, it was determined that an algorithm to trace these polygons could not be relied upon, and so they were traced by creating new polygon features in ArcMap for each image. Area of these polygons was determined using ArcMap’s polygon measurement tool and are displayed in ha. The area of each lake was plotted against the year in which the image for that year was taken. All images were taken between May and September, so it is possible that there is an unknown influence of spring freshet or late summer evaporation for images for which the exact date is not known.

4.1.4 Area ANOVA

It was considered important to test if there was a significant difference in the areas of each lake over time. This comparison was performed with an Analysis of Variance (ANOVA), which was conducted using the aov() function in RStudio. Subsets of each lake were delineated by grouping them into categories defined by when the greatest change in area was observed, which were then compared for significant differences.

4.1.5 Area – weather variables

The areas of Isadore's Lake and Shipyard Lake were analysed alongside weather data to investigate a possible climatic influence. Correlations were checked for each weather variable (mean annual temperatures (°C), total annual rain (mm), total annual snow (mm), and total annual precipitation (mm)) and the area of the lakes using the pairs() function in RStudio. Linear models were then built taking the weather variables as predictors and the areas of Isadore's Lake and Shipyard Lake as response variables.

4.2 Sediment chemistry methods

4.2.1 Lake coring

Sediment coring occurred in mid-March 2016, when the lakes were ice-covered, with access gained by helicopter. Three replicate sediment cores were acquired from Shipyard (designated as S1, S2, and S3) and Isadore's Lakes (designated as I1, I2, and I3) using a Unitek push corer (Figure 4.2). A single core (P-NE20) was taken from NE20 for metal and sediment analysis. In addition, fifteen cores were collected within 5 m of the P-NE20 to create a single composite core (C-NE20) to provide the necessary sediment mass for dating, carbon, and nitrogen analyses be conducted by Jason Ahad, Natural Resources Canada, the scientific leader on this portion of the field survey. All of the cores had a diameter of 8.6 cm.

Cores were collected by lowering the push corer and pushing it into the soft lake sediment down to a depth of 50 to 60 cm. The corer was retrieved, and the bottom of the core tube plugged with a rubber bung prior to full removal from water to prevent sediment loss. Each core was inspected for sediment disturbance caused by the coring itself and, if no significant disturbance was found, was sealed and later sectioned at the helicopter hangar in Fort McMurray within 3 hours of coring. Cores were stored in a 4˚C refrigerator prior to sectioning in the helicopter hangar for Shipyard and Isadore's Lakes and in the NHRC equipment storage area in Saskatoon for NE20.

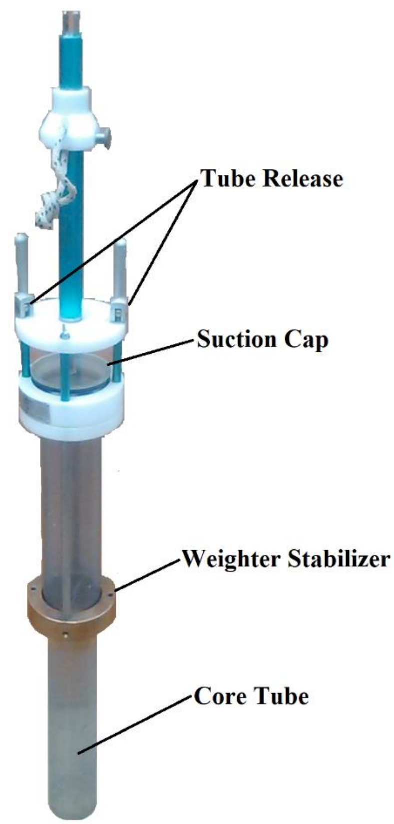


Figure 4.2: Push corer used to retrieve sediment cores.

Each core was sliced at specific intervals using a custom extrusion mount. The sectioning interval was 0.5 cm for the top 20 cm and was increased to 1 cm at greater depths. Intervals were measured with pre-calculated ‘fingers’. To avoid loss of sediment, separation of slices was accomplished with a metal ring of equal diameter to the core tube placed at the top of the core tube. Material was then extruded from the core into the metal ring, and the extruded material was separated from the rest of the core by sliding a stainless-steel spatula between the metal ring and the core tube. The slice was then deposited into a pre-labelled Whirl-Pak bag with a silicone spatula. The Whirl-Pak bag was immediately sealed and frozen prior to shipment.

4.2.2 Core handling and percent water methods

In the laboratory, each slice was weighed to determine the sediment wet weight. Slices were then freeze-dried using a Labconco FreeZone 18 at NHRC and reweighed to provide an estimate of sediment dry weight. The difference in wet and dry weight was used to calculate percent water content for each slice. All three Shipyard and Isadore’s cores were treated in this manner in addition to the single core collected at NE20. The freeze-dried slices from one core each from Isadore’s and Shipyard were sent to Queen’s University for analysis of Pb-210, Cs-137 and chlorophyll. The same core was also analyzed for total carbon, metals, and magnetic susceptibility. Magnetic susceptibility analyses were also conducted on S2, S3, I2, and I3. For NE20, metal analyses were conducted on P-NE20, while C-NE20 was used to measure the activities of Pb-210 and Cs-137, % mass concentrations of organic carbon and total nitrogen, as well as $\delta^{13}C$ and $\delta^{15}N$ isotope ratios. NE20 was not analysed for magnetic susceptibility since there was no need to correlate between cores as it was assumed that this upland lake would serve as a more stable depositional environment and thereby not exhibit significant spatial variation.

4.2.1 Dating

Age models for Isadore’s Lake and Shipyard Lake were developed from unsupported Pb-210 activities measured with an EG&G Ortec high purity germanium gamma spectrometer at the Paleoecological Environmental Assessment and Research Laboratory (PEARL) following the technique outlined in Appleby et al. (2001) and Schelske et al. (1994), and by Alberta Environment & Parks for NE20 on C-NE20 by J. Ahad due to limitations in sediment supply. From each lake, 20 to 25 sediment slices were selected for radiometric dating. Three age models were developed: the constant initial concentration (CIC) model, for which a constant sedimentation rate is assumed (Shukla and Joshi, 1989); the constant rate of supply (CRS) model, which assumed that the supply of Pb-210 was constant, but the sedimentation rate was not required to be (Appleby and Oldfield, 1978); and the constant flux: constant sedimentation (CF:CS) model, which assumed that both a constant atmospheric flux of Pb-210 and a constant sedimentation rate were present (Bonotto and García-Tenorio, 2014).

Gamma-count measurements of Cs-137 activity were made to corroborate the Pb-210 age models, since in undisturbed sediment, peak Cs-137 activity corresponds to peak fallout of Cs-137 in the year 1963-1964 and can serve as a marker for that time period (Jaakkola et al., 1983). If the Cs-137 derived depth for 1963-1964 and the Pb-210 derived depth for 1963-1964 are within the margin of error of each other, they are considered to be consistent. It is possible for Cs-137 to become mobile in sediment and migrate down-core as a result of physical or biological mixing, in which case the expected peak in activity may appear flattened (Jaakkola et al., 1983; Krishnaswamy et al., 1971). Following comparison of the models to the Cs-137 peak, the CRS models were found to provide the best available date estimation (Appleby and Oldfield, 1978; Robbins and Edgington, 1975).

4.2.2 Sediment grain size

Particle size distribution between the silt, sand, and clay fractions was determined using the pipette method for Shipyard and Isadore's Lake. This required the initial dissolution of organic matter from 10 g samples using 30% hydrogen peroxide (Pansu and Gautheyrou, 2007). With the sample in a 500 ml glass beaker, 100 ml of 1% H_2O_2 was added and the mixture was allowed to sit for one hour at ~4C, avoiding agitation. The temperature was then increased to 60˚C and small aliquots of 30% H_2O_2 were added. This was continued until effervescence ceased, and the supernatant became discoloured. The temperature was then increased to a controlled boil to eliminate excess H_2O_2 without allowing the sample to dry from boiling. The remaining sample was dried in a desiccation chamber, and a subsample of material <63 microns in diameter was taken by mechanical sieving.

The subsample, now devoid of organic matter and sand-sized particles, was then added to 500 ml glass vials, distilled water was added up to ~150 ml, and 10 ml of 30% sodium hexametaphosphate ($(NaPO_3)_6$) was added as a dispersing agent. These vials were then subjected to 12 hours of agitation on a hand-over-hand shaker. Following this, the samples were transferred to 500 ml glass fleakers, and distilled water was added to 400 ml. Each fleaker was manually agitated for a period of two minutes, and then left in an undisturbed state for a period of time related to the ambient temperature of the room, and thereby, the behaviour of particles in a viscous fluid, as described by Stokes' law (Gee and Or, 2002). Temperature was measured for each sample set individually, as it varied by up to 2˚C. After this waiting period, a 10 ml aliquot of sample was withdrawn from each fleaker, representing a fraction of the sample in which only clay is present. This clay subsample was added to a 50 ml beaker and dried in a 300˚C oven for 12 hours. After this, the sample mass was determined, which allowed calculation of the silt-clay ratio. Since the mass of sand, and therefore percent composition, was already known, this allowed calculation of the percent of silt, sand, and clay.

For NE20, the silt and clay fractions could not be measured with the pipette method due to the limited amount of sediment available. Instead, the percentages silt and clay were measured using a HORIBA LA 950 laser scattering particle-size distribution analyser (PSA). This method required that the concentration of clay was low to negligible and was deemed suitable for NE20 based on observing sediment samples from it. A 0.2 g subsample of each sediment slice was measured into a plastic dish. The HORIBA PSA was then activated and began drawing water into its reservoir dish. The subsample was delivered into the reservoir, from which point it entered the machine and was sonically agitated to ensure that flocculation of minor clay material would not influence analysis of particle size. The sample was then passed through a laser and the amount of light scattered by particles was measured and used to determine the particle size composition of the sample according to Mie scattering theory, in which larger particles will focus light forward while smaller particles will scatter it in all directions (Eshel et al., 2004; Konert and Vandenberghe, 1997).

4.2.3 Magnetic susceptibility

Magnetic susceptibility analyses were conducted on the three cores collected from each of Shipyard Lake and Isadore's Lake following (de Jong et al., 1998; de Jong et al., 2000). These magnetic susceptibility analyses were performed to correlate depths between cores within each lake to determine if there were spatial variations in deposition, as well as to evaluate trends in the deposition and formation of magnetic minerals in these lakes (Thompson et al., 1975). A Bartington MS2D meter was used to measure low frequency (0.47 kHz) and high frequency (4.7 kHz) magnetic susceptibility (Koroluk and de Boer, 2007). The MS2D meter was calibrated using an empty 10 ml glass scintillation vial blank, such that baseline magnetic response values ranged from -0.30 to 0.30 10^8 m^3/kg. Up to 10 g of sample was deposited into a 10 ml glass scintillation vial, and the height of the sample in the vial was measured to calculate height factor. The mass of sample was recorded. The sample vial was inserted into the meter and measured twice at low frequency. The sample was then removed, and another blank measured and recorded. The machine was then switched to high-frequency mode, and the same process was followed for high frequency settings. The resulting measurements of low and high frequency magnetic susceptibility were then used to calculate total magnetic susceptibility.

4.2.4 Total carbon

Total carbon was determined on cores I1 and S1 from Shipyard Lake and Isadore's Lake using the loss on ignition (LOI) procedure (Wang and Anderson, 1998). This procedure was performed by the SRC Analytics Saskatoon laboratory. A 0.4 g subsample from each slice was dried overnight at 105˚C, weighed and then heated to 1350˚C for up to 6 minutes, at which point all soil carbon would have combusted and released as CO_2. The sample was allowed to cool and was reweighed with the loss in mass being the total mass of carbon. During heating, CO_2 release was recorded with a LECO CR-12 carbon analyzer. This procedure was not used to measure the carbon content of NE20 due to the limited sediment available from its primary core.

4.2.5 Chlorophyll

Chlorophyll, used here as a proxy for primary productivity, was determined for the cores from Shipyard Lake and Isadore's Lake using visible reflectance spectroscopy (VRS) at the Paleoecological Environmental Assessment and Research Laboratory (PEARL) at Queen's University following Das et al. (2005). This process involved the analysis of the proportion of light of specific wavelengths reflected by the sediment sample. Reflectance spectra over the 650-

700 nm range, representing peak reflectance for chlorophyll, were measured with a FOSS NIR Systems Model 6500 series Rapid Content Analyzer. The sum of the reflectance spectra within this range was used to infer a dry weight concentration of chlorophyll as Chl α for each sample layer to a depth of 40 cm. The dry weight concentrations of Chl α were used to evaluate historical trends in lake primary productivity in Shipyard Lake and Isadore's Lake, as Chl α has been established as a suitable proxy for the direct measurement of this property (Michelutti and Smol, 2016).

4.2.6 Nitrogen content

Total nitrogen content of Shipyard and Isadore's Lake was measured by ALS Environmental. The sample was ignited in an Elementar vario MAX cube combustion analyzer in which the sample is first combusted in a pure oxygen environment at >1100℃ to release NO_x and N_2. These gases are then fed into a Cu reduction zone through a pure He environment to reduce all NO_x to N_2. This reduced nitrogen gas is then measured using a thermal conductivity detector following the Dumas method (Carter and Gregorich, 2008).

4.2.7 Metal concentrations

Concentrations were determined for a suite of 44 metals in the labile fraction (by partial digestion) and 53 metals in the total fraction (by total digestion) using ICP-MS technology (Li 1997) by the SRC Analytics Saskatoon Laboratory. Both total and labile fractions were measured for the majority of metals tested, with the total fraction representing the complete sum of metals in a sample including metals contained within sediment grains (the refractory partition), while the labile fraction only included the concentrations of metals adsorbed to the surface of particles. Results were reported based on the labile fraction of the metal, with the exception of Al, Ca, Fe, and Mn, as these metals are primarily concentrated within the refractory partition of sediment and were more useful as references for broad trends in sedimentation, particularly in the case of Al which is representative of the clay fraction (Ho et al., 2012). This use of the labile portion for assessing the metal content of floodplain lakes follows Cooke et al. (2017).

For analysis, 0.5 to 5 grams of each sample, depending on availability, were jaw crushed and then subsampled and pulverized with a puck-and-ring grinding mill. For the total fraction, subsamples were digested with an ultra-pure concentrated acid solution of hydrofluoric acid, nitric acid, and perchloric acid ($HF:HNO_3:HClO_4$), followed by analysis on a PerkinElmer Optima 5300DV ICP-OES. For the labile fraction, ultra-pure concentrated nitric and hydrochloric acids ($HNO_3:HClO_3$) were used to digest the subsample followed by analysis on a Perkin Elmer Elan DRC II ICP-MS or Perkin Elmer NEXION ICP-MS. Metals were reported as their elemental concentration in μg/g. A subset of these metals was selected for further analysis in this study based on their relevance to the oil sands (Pb, V, Ni, Ca), existence of CCME sediment guidelines (As, Cu, Pb, Hg, Zn), usefulness as a standardization factor (Al), or mobility within the sediment due to changing redox conditions (Fe, Mn).

To compare metal concentrations as measured in the present study to those determined in these same lakes in previous studies, the upper 2 cm of sediment from NE20, Isadore’s Lake, and Shipyard Lake was selected. Core P-NE20 from NE20 was compared to metal concentrations in the top 2 cm of cores taken by Cooke et al. (2017), and Isadore’s Lake and Shipyard Lake were compared to the most recent 5 years of grab samples, 2011 – 2015, taken by RAMP (Hatfield Consultants et al., 2016a). The average metal concentration for these sections was calculated and a ratio between the average concentrations of each metal in the matching lakes was calculated. Data for all metal concentrations measured may be found in Appendix B.

5. Results and discussion

5.1 Introduction

In this chapter, the key results from both the geomorphology component and the sediment chemistry component of this thesis will be presented. The results of the geomorphology component include analyses of weather trends at Fort McMurray, water levels and the occurrence of floods in Isadore's Lake and Shipyard Lake, and an analysis of lake area over the past century for both lakes. The results of the sediment chemistry component will begin with a brief overview of the major sediment chemistry features of NE20, Isadore's Lake, and Shipyard Lake, followed by the results of physical and chemical analysis of each lake. The results of the physical and chemical analyses of each lake will include grain size distribution, water content, carbon content, nitrogen content, 210-Pb age model, and an analysis of metal concentrations through time as represented by concentration profiles. The sediment chemistry component results will be concluded with a comparison of metal concentrations determined for this study to previously reported values.

This will be followed by an interpretation of the results of the geomorphology and sediment chemistry components. The interpretation of the geomorphology component will include possible factors influencing the observed increase in lake area for Isadore's Lake and Shipyard Lake, and an interpretation of the depositional history of Isadore's Lake and Shipyard Lake regarding the interaction between grain size and flood frequency. As pertains to the sediment chemistry component, the spatial heterogeneity apparent particularly in NE20 is discussed, as well as an interpretation of the results concerning the concentration of metals in recent sediments in NE20, Isadore's Lake, and Shipyard Lake. In the case of both components, the limitations of analysis are included, as well.

5.2 Geomorphology

5.2.1 Fort McMurray weather trends

Analysis of weather data collected at station Fort McMurray A (Table 5.1, Figure 5.1) shows a significant trend ($p < 0.0001$) in mean annual temperature between 1944 and 2007. Mean annual temperatures have increased at Fort McMurray A from ~-1 ˚C to 2˚C during this time period. No other weather variable considered showed a significant relationship during the period of monitoring.

Table 5.1 Model coefficients for models of weather variables measured at station Fort McMurray A between 1944 and 2007.

weather variable	intercept	slope	p
mean annual temperature (˚C)	-73.81	0.04	< 0.0001
total precipitation as rain (mm)	-545.93	0.44	> 0.05
total precipitation as snow (mm)	538.24	-0.20	> 0.05
total precipitation (m)	830.25	-0.20	> 0.05

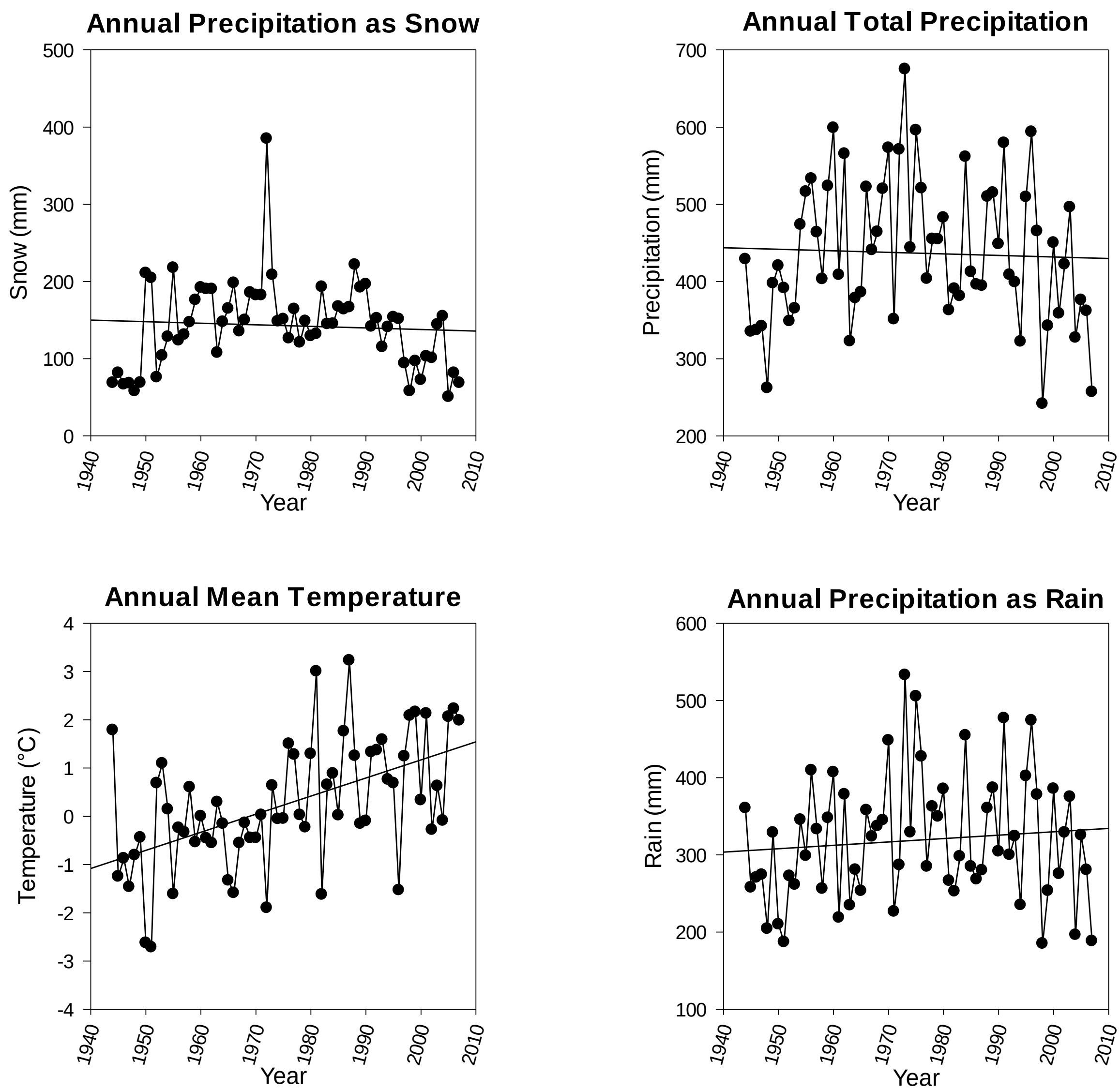


Figure 5.1 Weather variables measured at station Fort McMurray A between 1944 and 2007

5.2.2 Water level and flood occurrence

A comparison between the monthly maximum water level and flood limit for Shipyard Lake and Isadore's Lake (Figure 5.2) shows major differences in the frequency of open-water floods between the floodplain lakes. The flood limit for Isadore's Lake (242.0 m) is much higher than most of the maximum monthly water levels recorded at 07DA001, and therefore, Isadore's Lake would not be regularly susceptible to flooding during the open-water season. This high flood limit corresponds to what was indicated in previous surveys of the hydrology of this lake (Albian Sands Energy Inc. 2005). The flood limit of Shipyard Lake (240.1) would allow regular direct contact with the Athabasca River during the open-water season. This flood limit also agrees with previous hydrological surveys (Golder Associates Ltd. 1996), which indicated that Shipyard Lake would regularly receive high-volume, short-duration input from the Athabasca River.

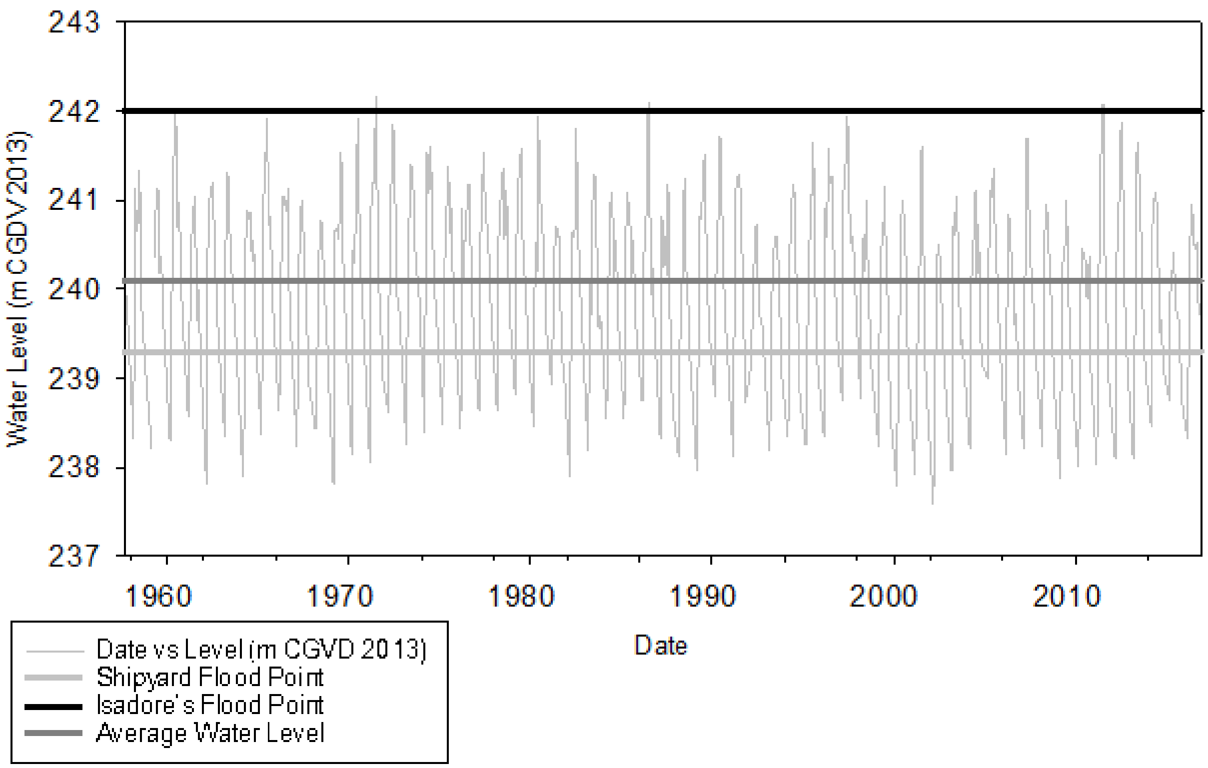


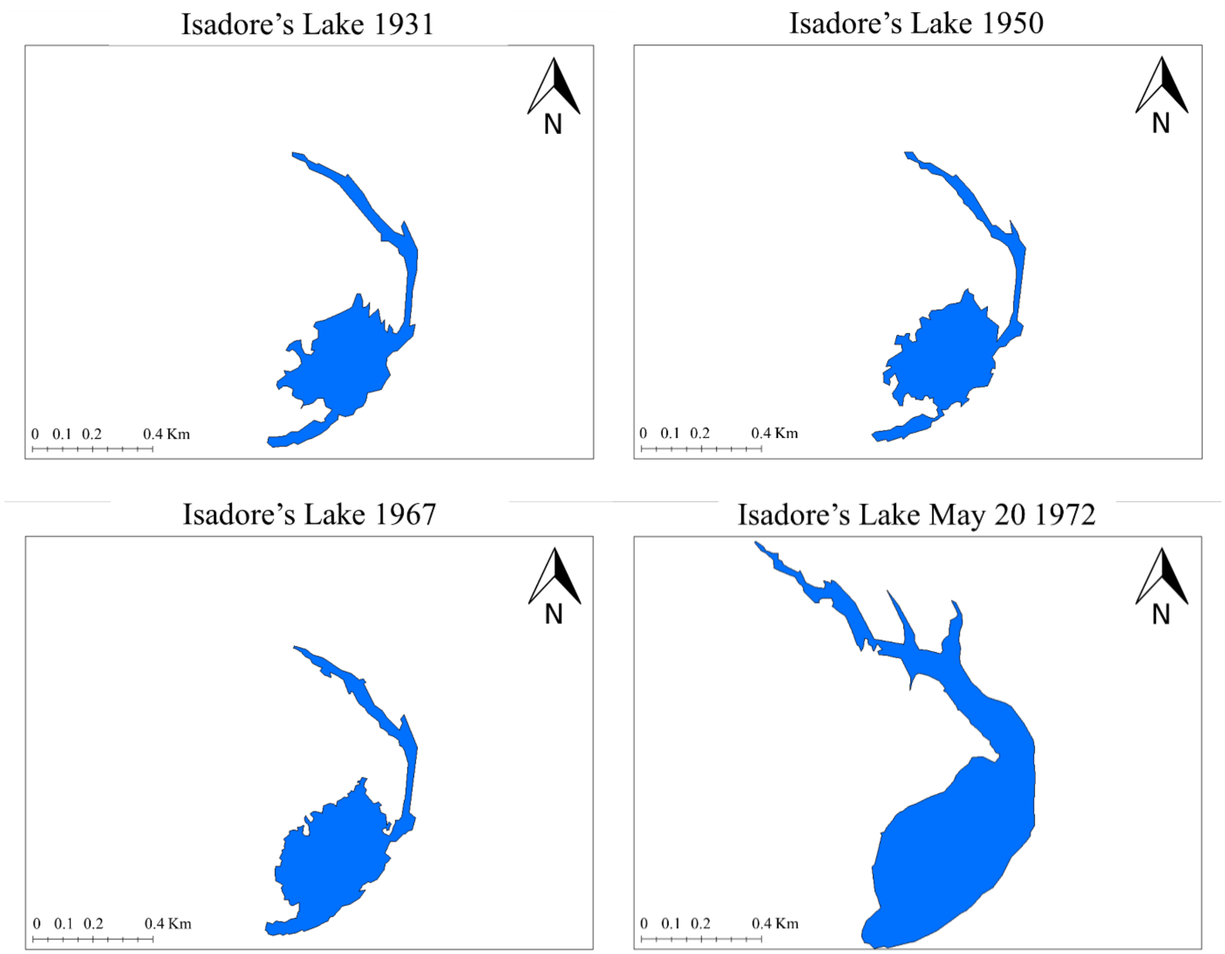
Figure 5.2 Maximum water level recorded each month at HYDAT station 07DA001 (Athabasca River below Fort McMurray), compared to average monthly water level (239.3 m), and required water level to flood Shipyard Lake (240.1 m) and Isadore's Lake (242.0 m).

5.2.3 Lake area

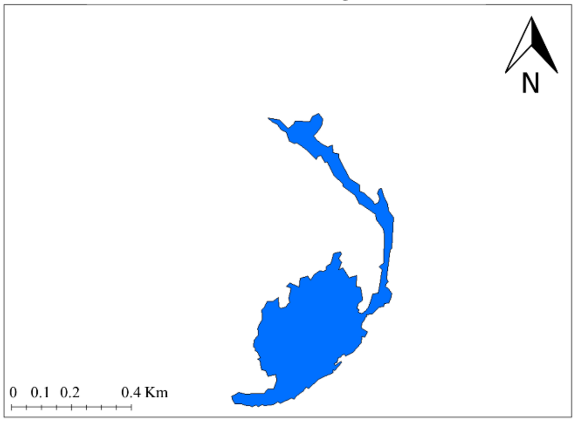
Isadore's Lake

Between 1985 and 1995 Isadore's Lake increased to 150% of the area apparent in the earliest images of it, which can be observed in outlines of the lake area for Isadore's Lake (Figure 5.3), and plots of digitally measured lake area over time (Figure 5.4). As with Shipyard Lake, no change in the position Isadore's Lake relative to the Athabasca River was observed in the record of aerial photographs, suggesting a stable riverbed.

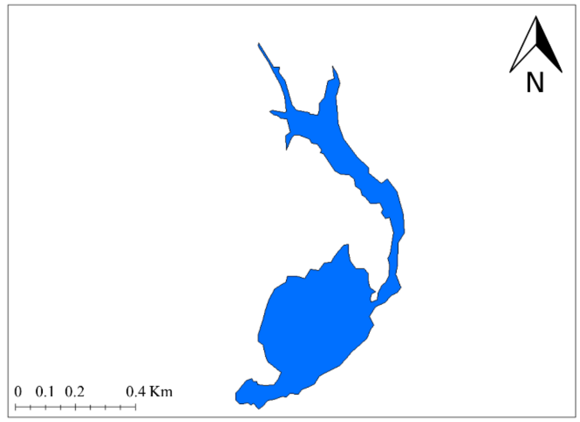
The lake area for Isadore's Lake ranges from 12.7 ha. (1939 and 1950) to much larger values in the range of 32.3 to 33.8 ha. in recent years (1994 to 2012) (Table 5.2). Observing the plots of lake area over time (Figure 5.4), it appears Isadore's Lake has increased in area. Assuming 1990 as a year with which to delineate early and recent groups of aerial photographs, ANOVA shows that the areas of the lake has significantly increased following this time (Table 5.4). In Isadore's Lake, a moderate positive correlation was found between lake area and mean annual temperature (Table 5.5), though no other correlations of meaningful strength were observed.



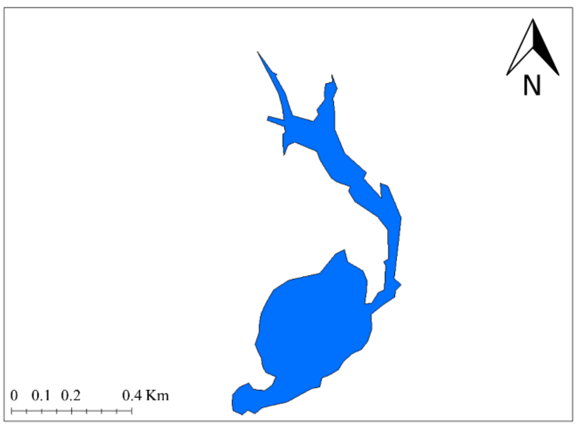
Isadore's Lake August 1974



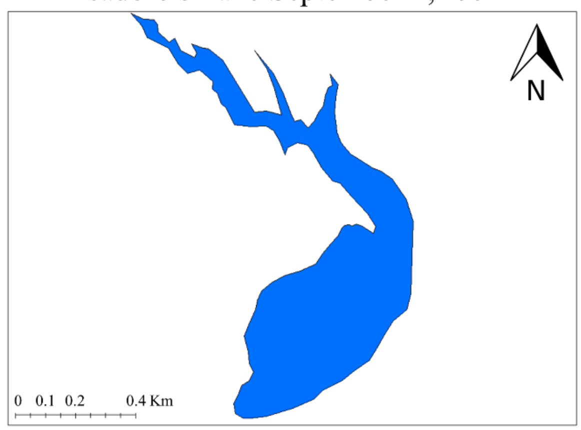
Isadore's Lake June 8,1980



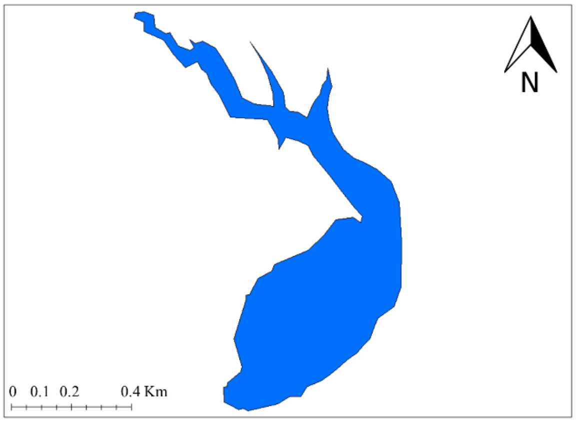
Isadore's Lake 1984



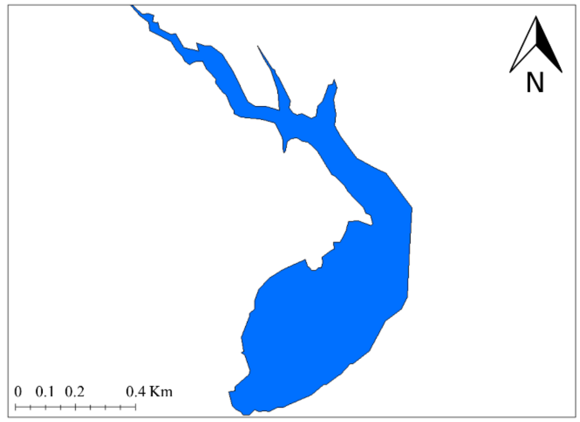
Isadore's Lake September 1, 1994



Isadore's Lake April 19, 1998



Isadore's Lake October 3, 2003



Isadore's Lake September 6, 2012

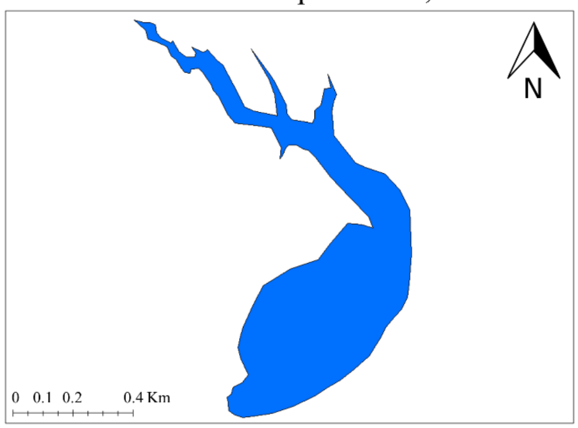


Figure 5.3 Outlines of lake area constructed from georeferenced images of Isadore's Lake taken from 1931 to 2012.

Table 5.2 Area of Isadore's Lake determined from aerial photographs

year	area (ha)
2012	33.7
2003	32.3
1998	33.6
1994	33.8
1984	20.0
1980	19.1
1974	14.9

1972	31.6
1967	14.8
1950	12.7
1931	12.7

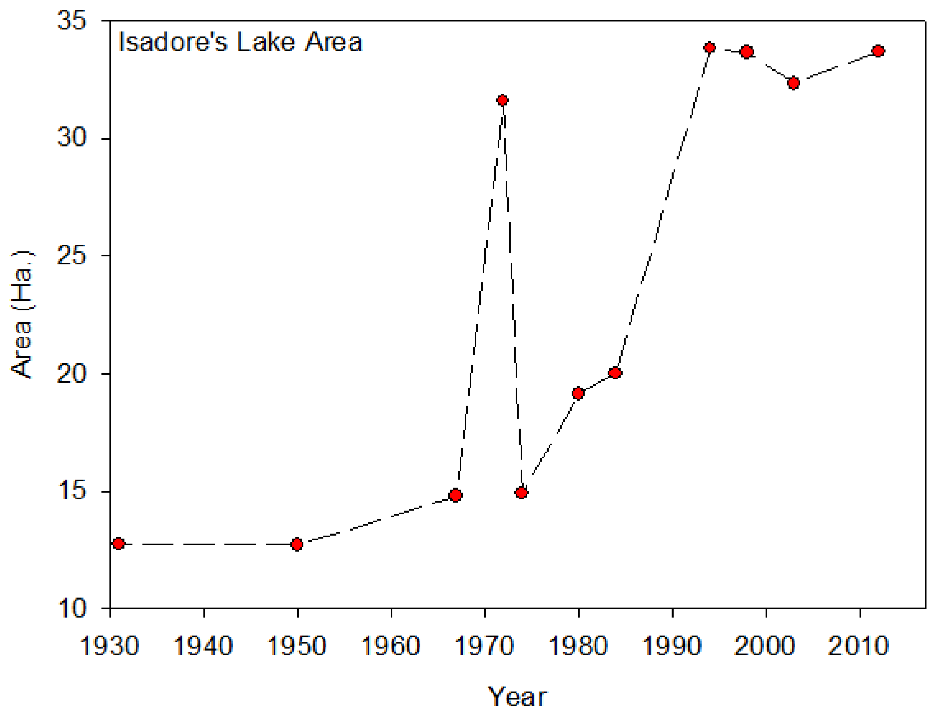
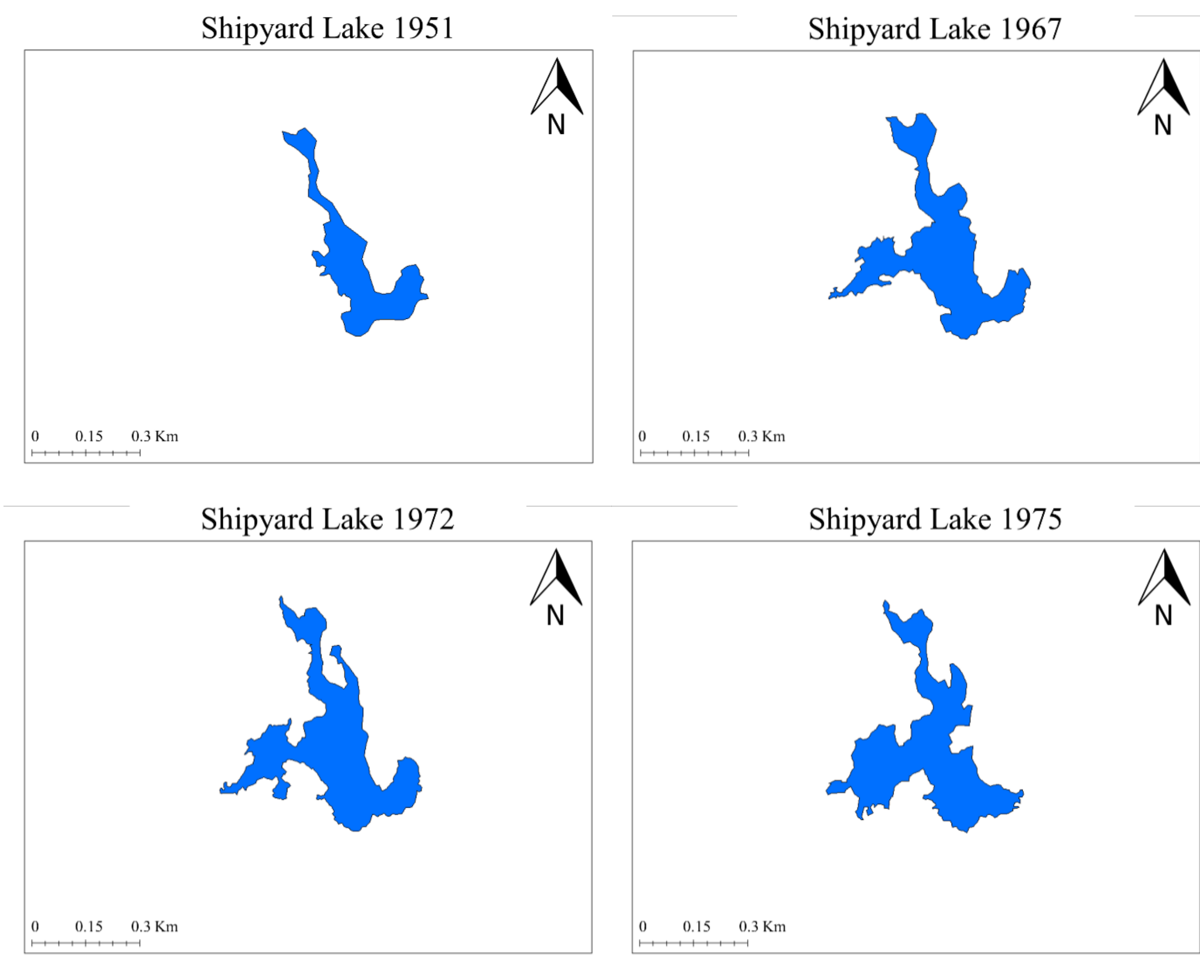


Figure 5.4 Plot of lake area (ha) over time for Isadore's Lake. Lake area was digitally measured from lake outlines in ArcMap.

Shipyard Lake

Between 1967 and 1984, the area of Shipyard Lake showed little variation and varied around 10 ha (Figure 5.5, Table 5.3). From 1984 onward, the lake area steadily increased from 12.7 ha. in 1990 to 21.3 ha. in 2012, 200% of the size observed in 1967 (Figure 5.5, Table 5.3). This increase in area appears to persist until present day and is present regardless of season. No change in the position of Shipyard Lake relative to the Athabasca River was observed in the record of aerial photographs, implying a stable riverbed.

The area of Shipyard Lake ranges from 5.22 ha. to 21.3 ha. between the earliest aerial photograph available in 1951 and the most recent available image taken in 2012 (Table 5.5, Figure 5.6). Shipyard Lake appears to have been increasing in area since the beginning of the record of aerial photographs in 1951, though from 1972-1980 there was no observable increase (Table 5.3, Figure 5.6). Assuming 1984 as a year with which to delineate early and recent groups of aerial photographs, an ANOVA test of lake area shows that the areas of the Shipyard Lake has significantly increased following this time (Table 5.4). In Shipyard Lake, a moderate positive correlation was found between lake area and mean annual temperature (Table 5.5), though, as with Isadore's Lake, no other weather variables had correlations of meaningful strength with lake area.



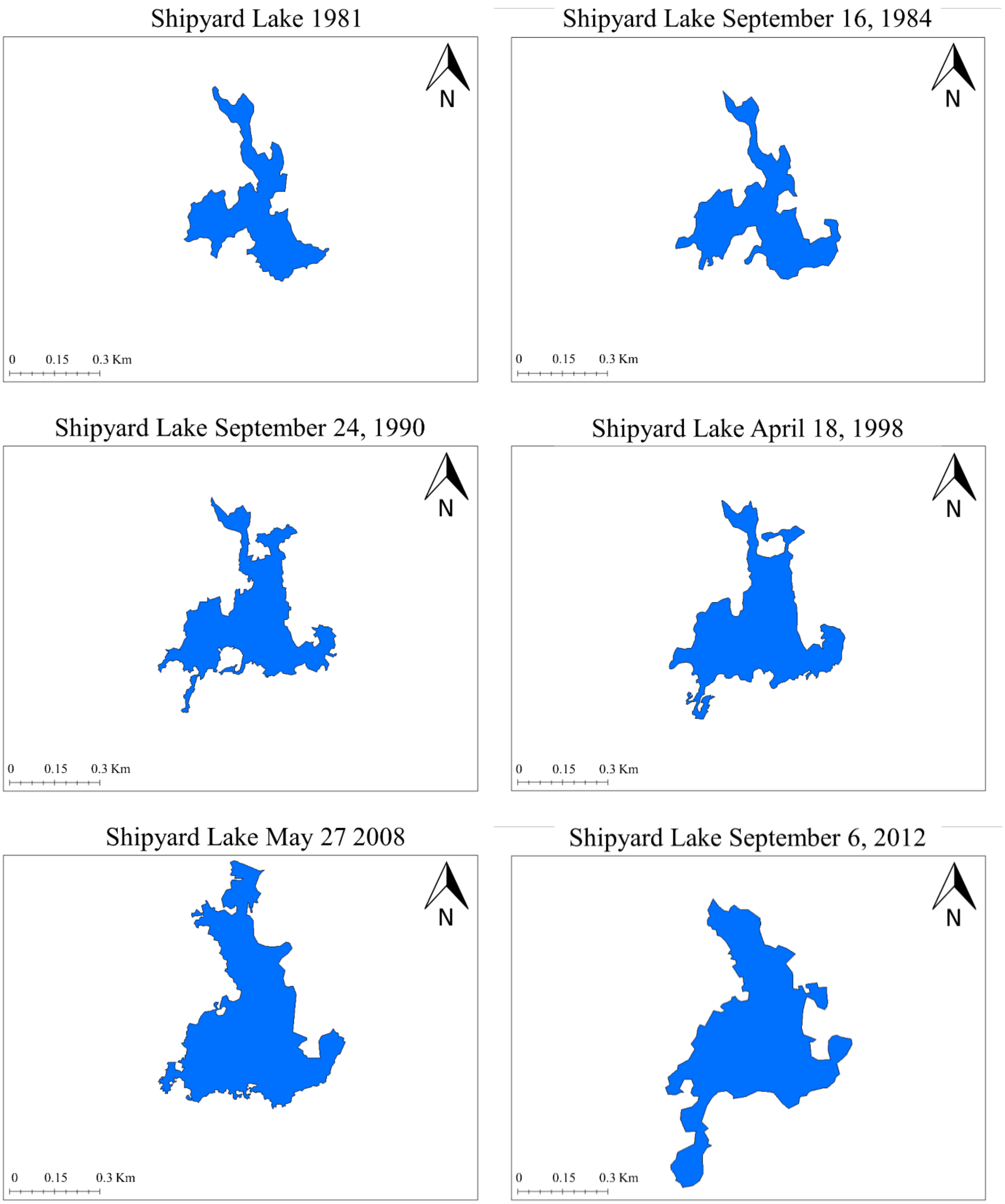


Figure 5.5 Outlines of lake area constructed from georeferenced images of Shipyard Lake taken from 1951 to 2012.

Table 5.3 Area of Shipyard Lake determined from aerial photographs

Year	Area (ha.)
2012	21.3
2008	20.1
1998	14.6
1990	12.7
1984	10.5
1981	9.45
1975	10.4
1972	10.4
1967	9.65
1951	5.22

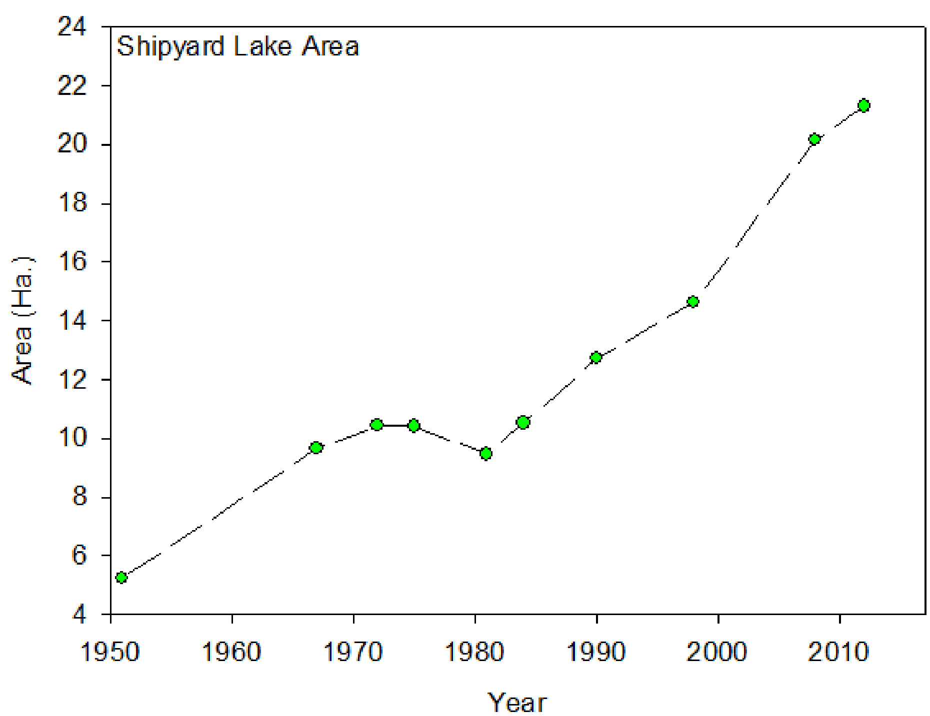


Figure 5.6 Plot of lake area (ha.) over time for Shipyard Lake. Lake area was digitally measured from lake outlines in ArcMap.

Table 5.4 ANOVA output for change in lake area, with groups defined as pre- and post 1984.

Lake	Df	F-value	P-score
Isadore's	1	20.37	< 0.005
Shipyard	1	16.51	< 0.005

Table 5.5 Spearman correlation between weather variables measured at Fort McMurray A between 1944 – 2007 and the area of Isadore's Lake.

Weather Variable	Isadore's Lake	Shipyard Lake
Mean Annual Temperature (˚C)	0.57	0.33
Total Precipitation as Rain (mm)	-0.17	0.02
Total Precipitation as Snow (mm)	-0.32	-0.19
Total Precipitation (m)	-0.1	0.07

5.3 Sediment chemistry

5.3.1 NE20

Grain size distribution

The NE20 sediment core had an average sand content of 34.8%, a silt content of 34.1% and a clay content of 2.5% (Figure 5.7). Percent sands had declined notably between 2-6 cm and 10-18 cm which correspond to visual observations of a reduction in organic matter. Throughout the core, small shells ranging from 2 – 3 mm diameter were observed. High %sand was observed from 6-9 cm depth, reaching a peak of 59.2% sand, as well as rising above 50% sand periodically below 18 cm depth. The highest %clay was observed from 4-6 cm depth and reached 12.9%, and below this %clay rose infrequently to 6-8%.

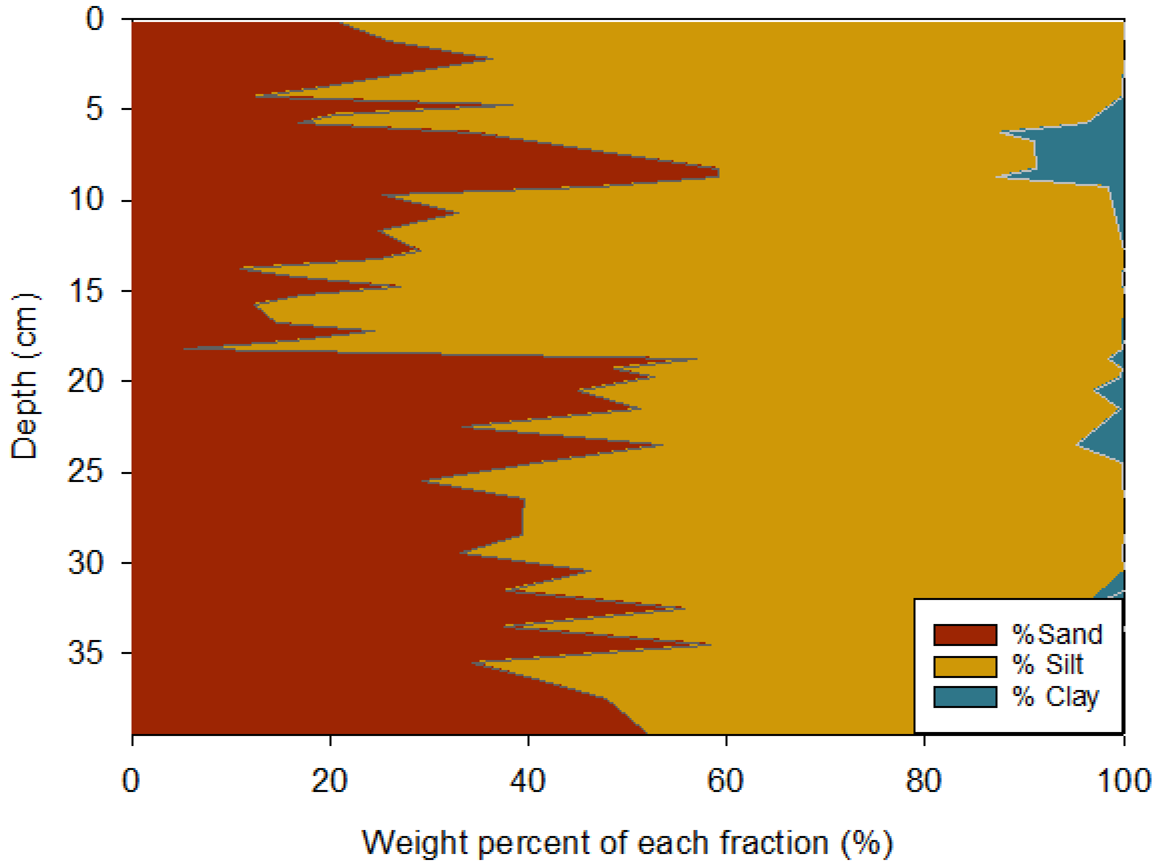


Figure 5.7 Particle size distribution of sediment core P-NE20 from NE20.

Water content

Water content in the primary sediment core was 60% at the surface, increased to 73% from the surface to 20 cm depth, and then increased to 83% from 20 – 40 cm. The water content of the composite core was unusually high at >90% throughout, possibly related to the high organic carbon content of this core (Figure 5.8). There was little variation in water content between the different cores which made up the composite core.

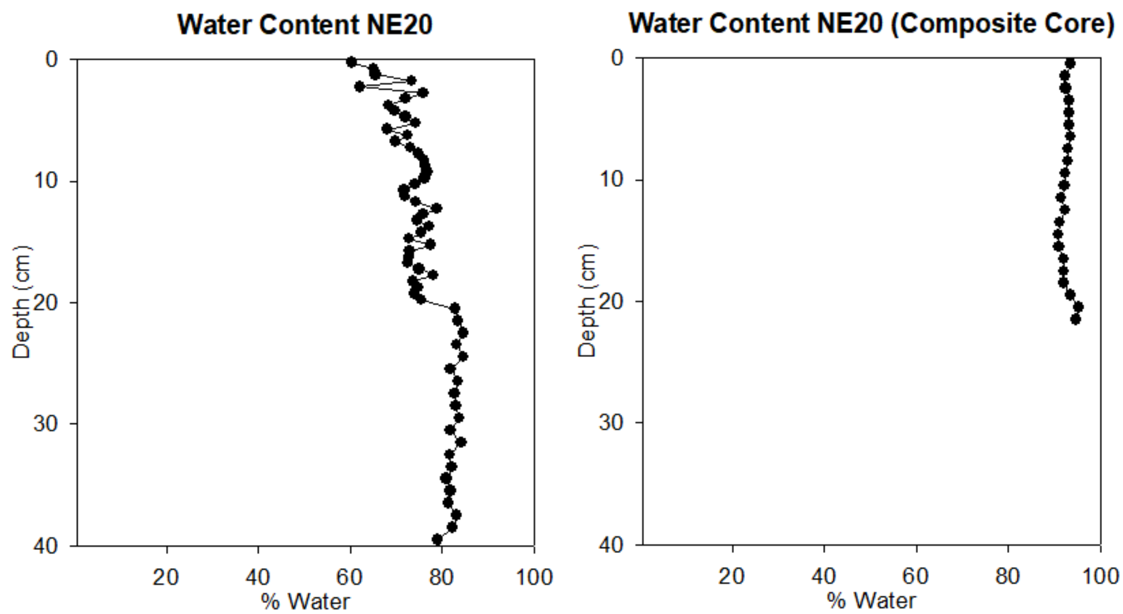


Figure 5.8 Water content by mass in the primary and composite cores of NE20, expressed as % mass.

Dating

Activity measurements of Pb-210 on C-NE20 from NE20 follow the decay curve expected from relatively undisturbed sediment, with o secondary peaks or other indicators of sediment disturbance observed (Figure 5.9). Peak activity of Pb-210 (366 Bq kg^{-1}) occurs at the surface and depletion to background activity is observed at 12 cm (Figure 5.9). Peak Cs-137 activity occurs between 4 and 5 cm, which corresponds to the CRS-derived date of 1971 ± 1.8 years (Figure 5.9). This date falls outside of error for the 1963-1964 Cs-137 peak. Some minor flattening of the peak activity of Cs-137 may be present. Based on the depth-age curve for C-NE20 (Figure 5.10), the advent of oil sands development over 1960-1970 is estimated to be recorded at 4 – 6 cm depth.

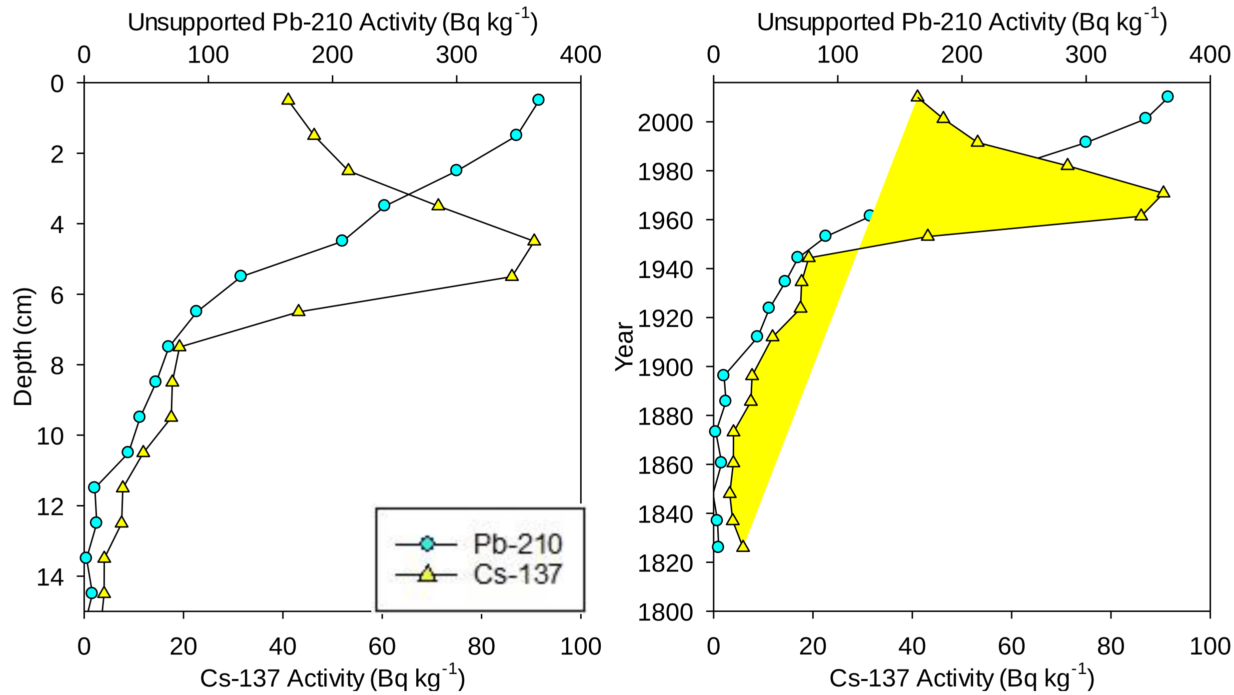


Figure 5.9 Profiles of Pb-210 and Cs-137 activity for NE20 indicate which core (Bq kg^{-1}) Show depth-age curve (depth on vertical axis) instead of the graph on the right.

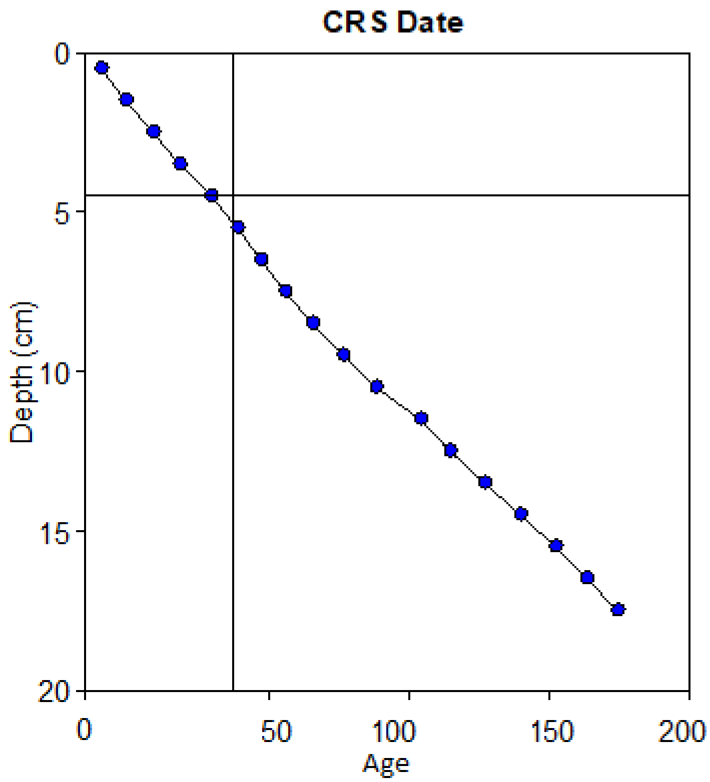


Figure 5.10 Depth-age curve of C-NE20 from NE20. Horizontal line indicates depth of Cs-137 peak, and vertical line indicates CRS date of 1963.

Metals

Among the temporal trends in metal concentrations observed in P-NE20 were marked increases in Al, Fe, Mn, As, Pb, Ni, and V above background concentrations in the top 5 cm of the core (Figure 5.11). The was an increase in the concentrations of Cu and Hg observed, as well, but these only minorly increased above background. Conversely, Ca and Zn decreased in concentration above 5 cm depth. The 5 cm depth of this sharp rise in concentration for these metals corresponds to 1961 on the age model determined from depth-age curve for C-NE20 (Figure 5.10). Notably, V rises from an average of 1.46 µg/g below 5 cm depth to 13.91 µg/g above 5 cm depth, while As increases from 0.641 µg/g to 1.321 µg/g in that same period (Figure 5.11)

The normalized metal profiles (Figure 5.11) show the concentration of Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn relative to the concentration of total aluminum. Measurements of V/Al increase slowly between 6.75-2.75 cm (1961-1987), at which point the enrichment becomes much more pronounced up to 1.25 cm (2001), before rapidly declining. Total change in V/Al in NE20 between baseline and peak is 737 $x10^6$, before declining to 719 $x10^6$ (Figure 5.11). It cannot be seen from this core if NE-20 has returned to background levels for V/Al. The enrichment in As is much more modest, peaks earlier than V, and has returned to background levels. Arsenic enrichment begins concurrently with V, rising from 249 $x10^6$ to a peak of 495 $x10^6$ in 1992. The profiles for metals observed here correspond to what was reported by Cooke et al. (2017), though with some variation in timing.

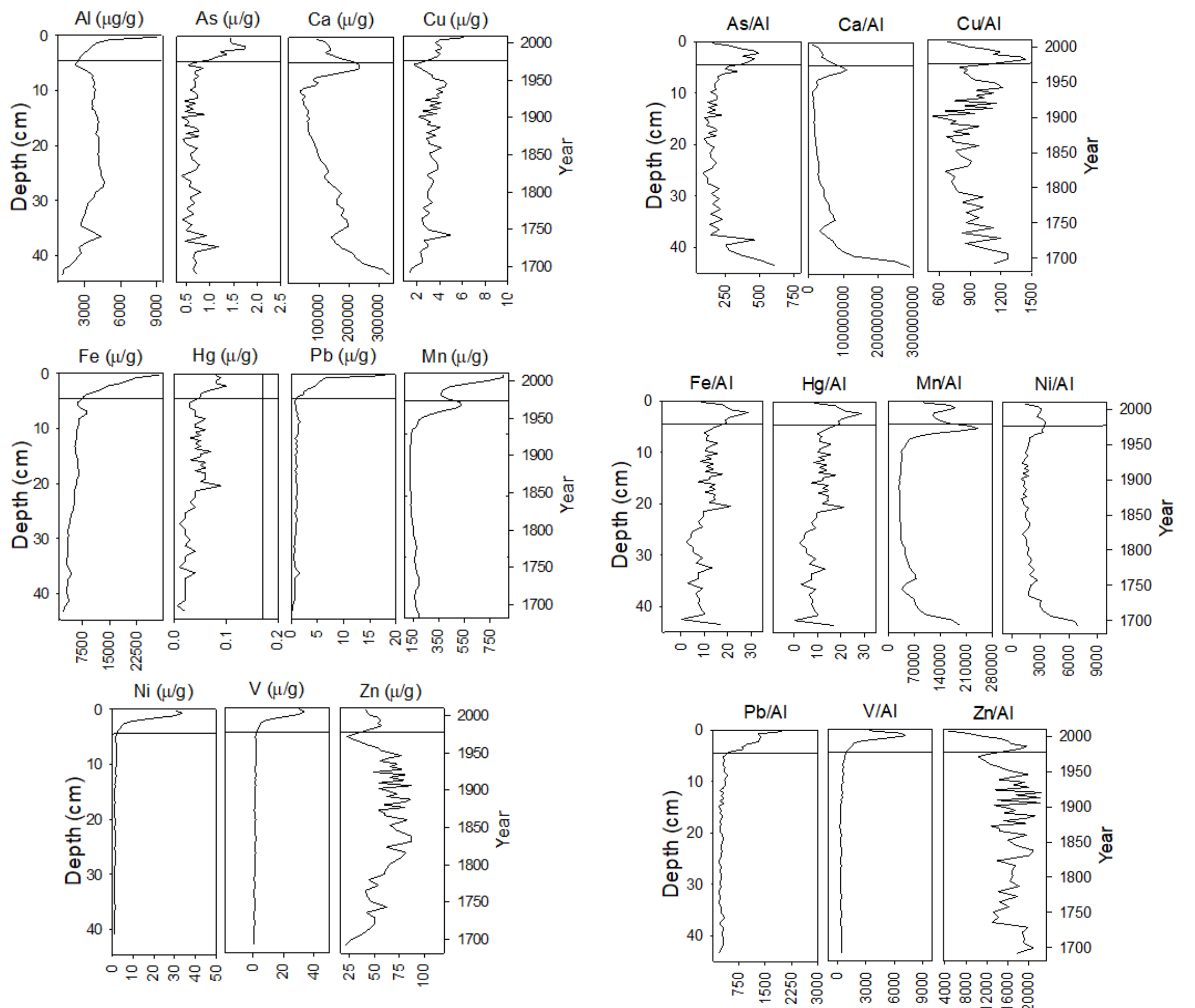


Figure 5.11 Profiles of metal concentrations for Al, Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn in NE20, expressed as µg/g (left). Profiles of Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn normalized to Al in NE20 expressed as the ratio of each metal's concentration to Al concentration (right).A horizontal line shows the depth of the 1963 peak in atmospheric Cs-137 fallout.

5.3.2 Isadore's Lake

Grain size distribution

The Isadore's Lake core I1 was dominated by sand with an overall average content of 56.1% with a higher average concentration of 65.0% in the upper 20 cm and 40.2% at 20-40 cm (Figure 5.12). Silt (21.7%) and clay (35.3%) were relatively stable throughout the core, although silt content accounted for only 15.0% in the upper 20 cm of the core and 35.2% in the lower 20-40 cm. A send lens was observed from 5 – 10 cm with an average of 80.2% sand. Below this, from 14 – 20 cm %sand was observed to alternate between similarly high levels around 80% to lower levels near 55%. Clay content remained similar to its overall average throughout the core.

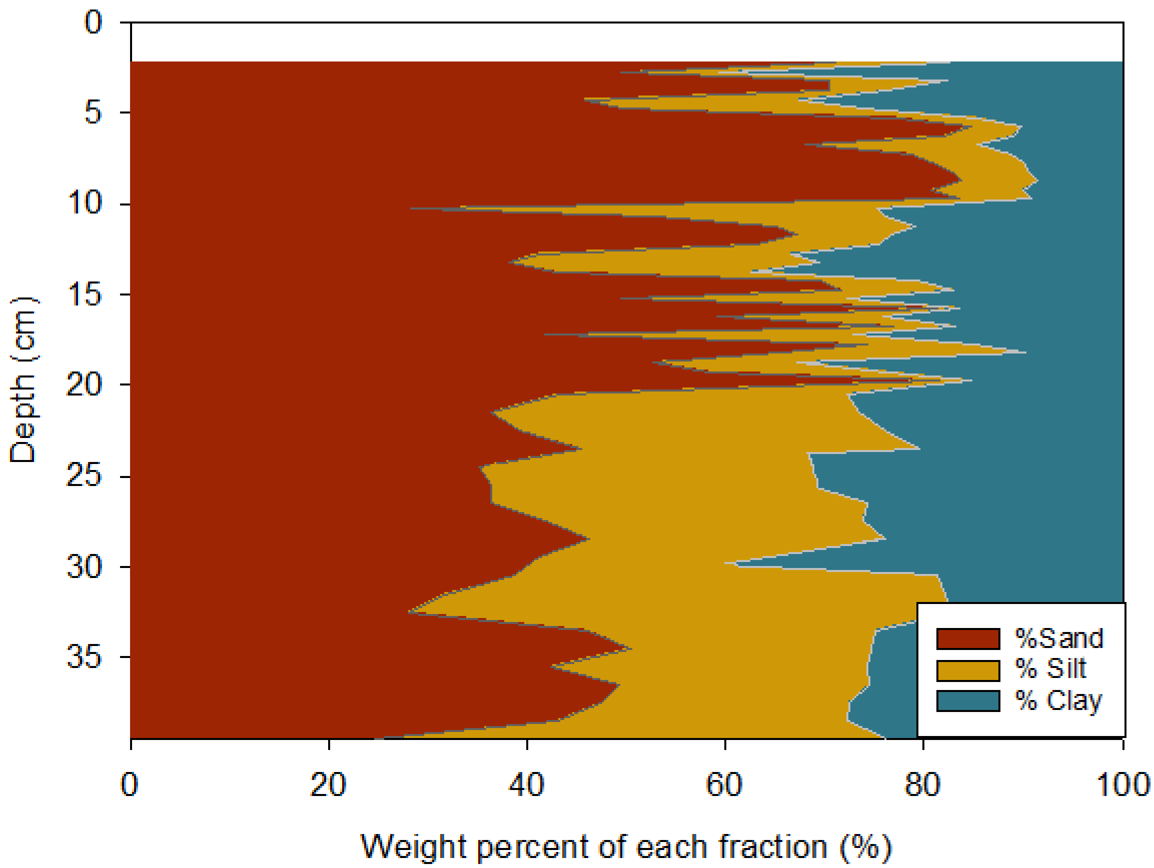


Figure 5.12 Particle size distribution of sediment core I1 from Isadore's Lake.

Water content

A steep decline began at the surface with water content decreasing from 90% to <50 % at 10 cm depth, followed by an increase to concentrations found near the surface, observed in all three cores taken from Isadore's Lake (Figure 5.13). Following this, water content decreased irregularly with depth to reach < 50% at the bottom of each core.

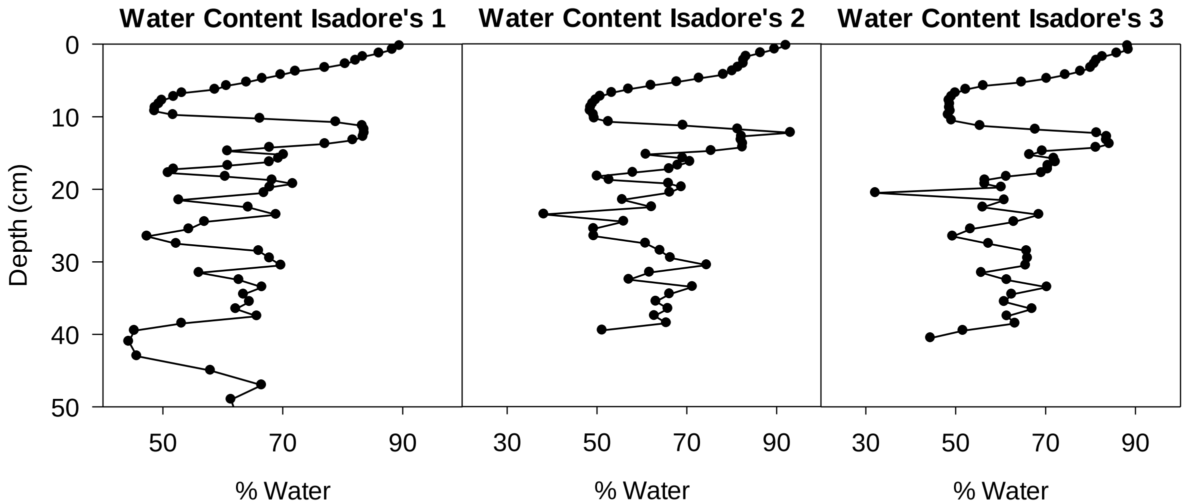


Figure 5.13 Water content by mass in each core taken from Isadore's Lake, expressed as %.

Magnetic susceptibility

Some minor differences were observed in magnetic susceptibility measurements between cores in Isadore's Lake (Figure 5.14). Values for magnetic susceptibility ranged from 0.49 – 15.6 x10^8 m^3/kg in I1, 0.51 – 16.1 x10^8 m^3/kg in I2, and 0.74 – 16.7 x10^8 m^3/kg in I3. Strong correlation between cores within Isadore's Lake can easily be observed, with peaks in measurement occurring at equal depths of 6 cm, 15 cm, 24 cm, and 31 cm, though the 31 cm peak does not appear in I3.

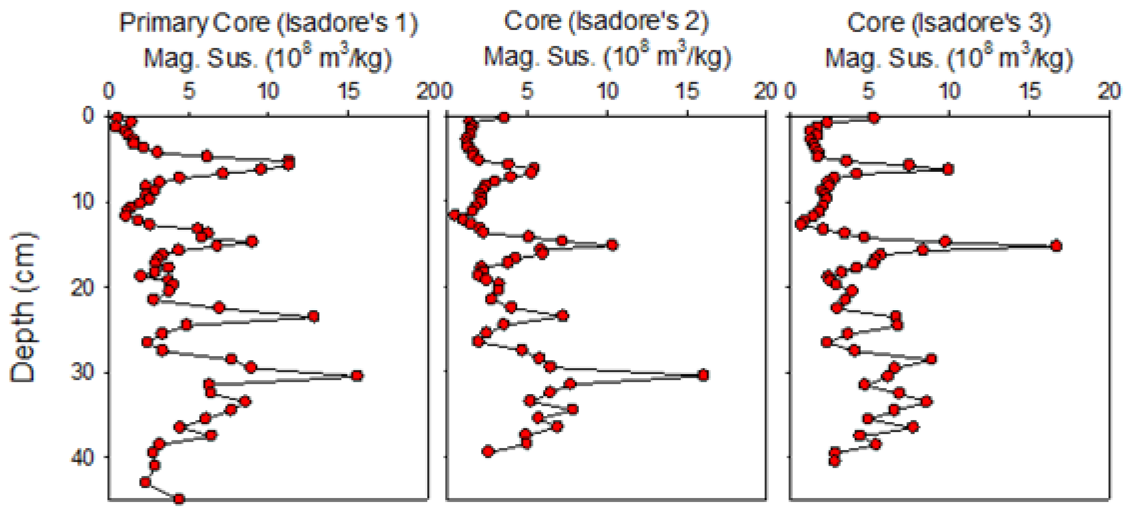


Figure 5.14 Magnetic susceptibility in each core taken from Isadore's Lake, expressed as 10^8 m^3/kg.

Dating

Pb-210 activity in Isadore's Lake was observed to be extremely low in core I1 (~100 Bq kg^{-1}). Multiple distinct peaks in Pb-210 activity were observed at 1.25 cm, 11.25 cm, and 11.75 cm depth (Figure 5.15). From 5 – 10 cm there is a marked reduction in the activity of Pb-210, which corresponds a sand lens (Figure 5.12). The Pb-210 decay curve as seen here is not ideal for determining an accurate age model.

Peak Cs-137 activity occurred at 16.75 cm midpoint depth, which corresponds to the CRS-derived date of 1964 ± 14 years (Figure 5.16). This corresponds neatly to the 1963-1964 Cs-137 test ban treaty peak (Jaakkola et al., 1983). On the other hand, it is possible that there has been some flattening of the Cs-137 peak, which introduces further error into the use of Cs-137 as a reliable marker in Isadore's Lake. Due to possible flattening in the Cs-137 profile and the non-ideal Pb-210 profile, this age model cannot be relied upon.

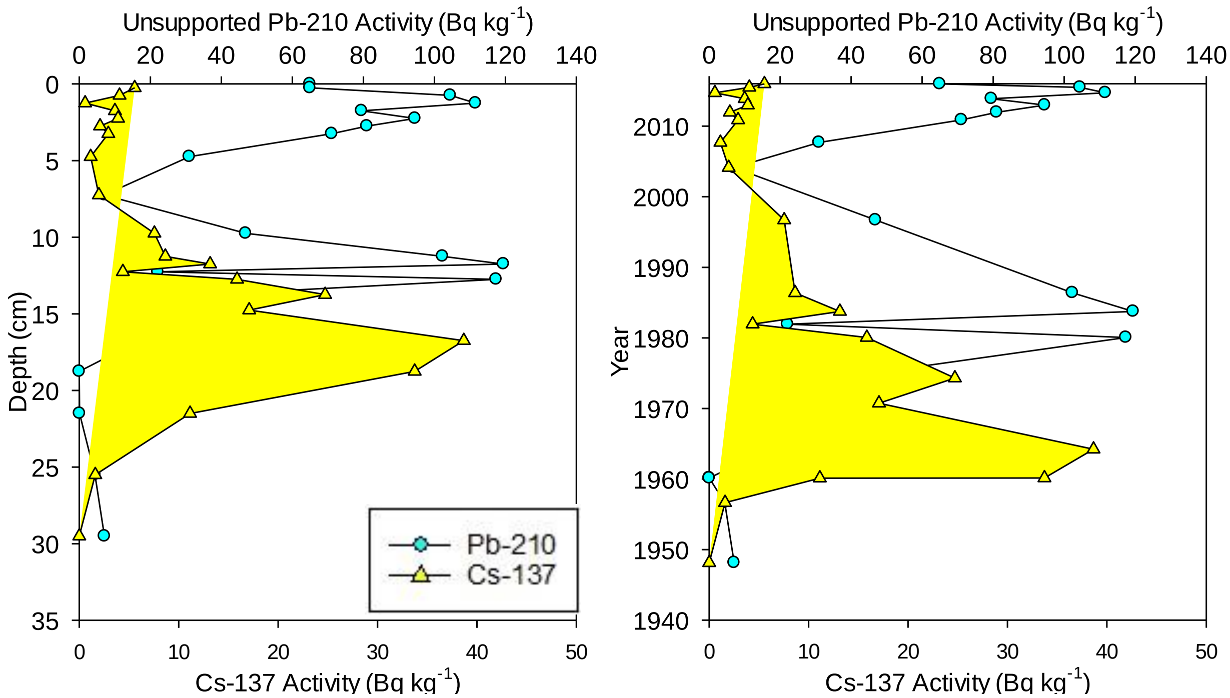


Figure 5.15 Profiles of Pb-210 and Cs-137 for Isadore's Lake (Bq kg^{-1}).

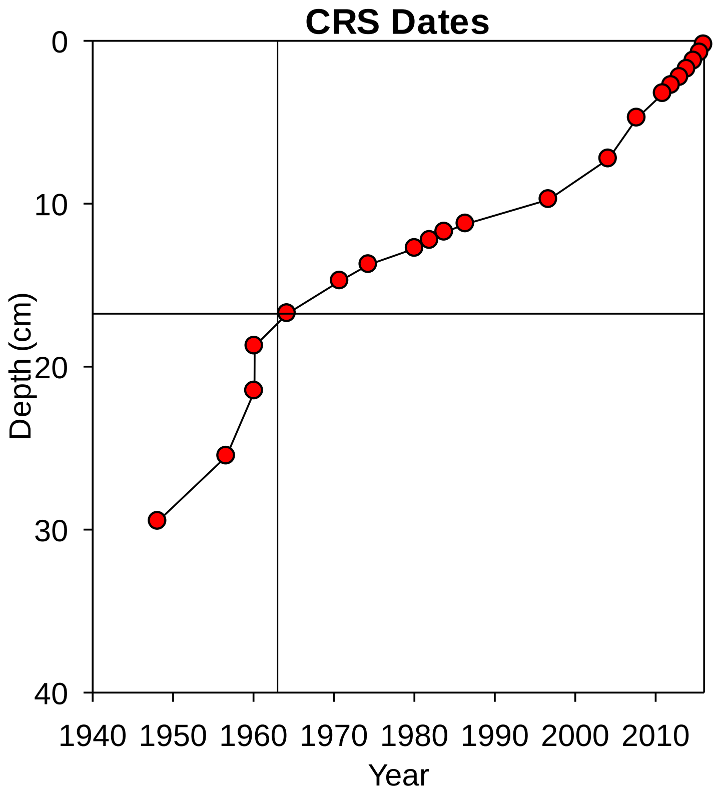


Figure 5.16 CRS model results for Isadore's Lake. Horizontal line indicates depth of Cs-137 peak, and vertical line indicates CRS date of 1963.

Metals

In Isadore's Lake, all metals except Mn showed minimal long-term change in concentration, and either decreased (Al, Cu, Pb, Ni, and Zn) or increased (As, Ca, Fe) at 12-14 cm depth, then returned to background at 12 cm depth (Figure 5.17). Arsenic concentrations in Isadore's Lake during this period of enrichment from 13-14 cm depth surpassed the ISQG (7.24 µg/g), but not the PEL (41.6 µg/g) CCME guidelines for sediment quality. However, ISQG was also exceeded for As deep in the core, indicating that these conditions could occur pre-oil sands development (CCME, 1995). For the majority of the core, the ISQG guideline was surpassed for As in Isadore's Lake. No other metals analysed were observed to surpass ISQG guidelines.

In Isadore's Lake, between 15.25-13.75 cm, the concentration of V/Al rapidly rises, increasing from ~273 x10^6 V/Al ppm to 562 x10^6 V/Al ppm, before returning to previous levels (Figure 5.17). During this period, we see a concurrent rise in concentration for As/Al; increasing from 62.4 $x10^6$ to 442 $x10^6$, as well as for Ca/Al, which increases from 4.62 $x10^{11}$ to 5.11 $x10^{12}$. Each of these metals then declines in enrichment before returning to background levels at a depth of 11.25 cm. following this period of enrichment, neither As nor V rise above background concentration for the remainder of the core.

Normalized Mn and Fe each show a minor increase in concentration beginning at 5 cm depth, though this rise is indistinguishable from concentrations observed in the deeper sections of the core (Figure 5.17). As with V/Al and As/Al, Fe/Al and Mn/Al show a large increase in concentration at 15.25-13.75 cm depth. An additional peak in Mn/Al is observed at 34 cm depth which is not present in Fe/Al.

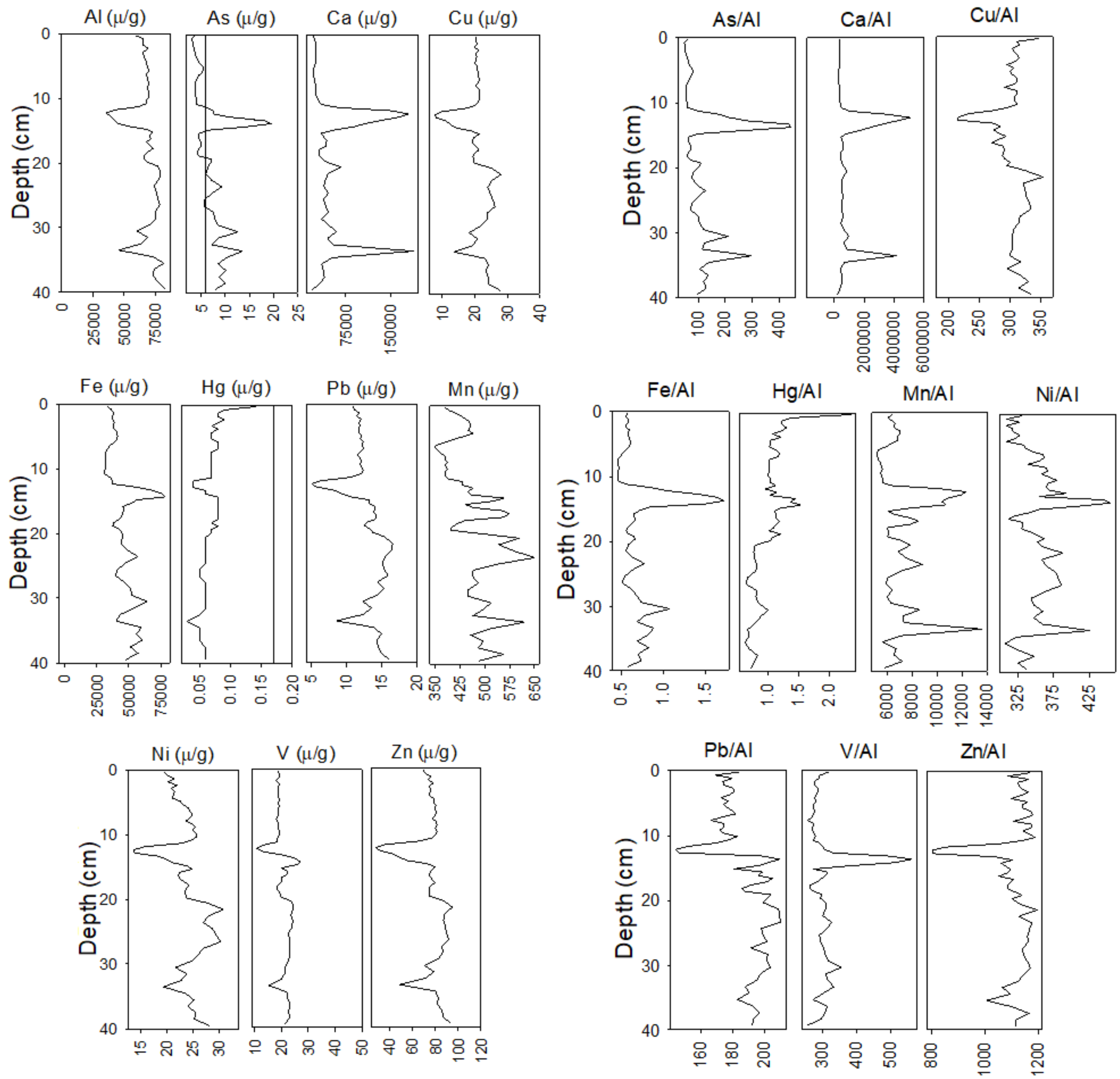


Figure 5.17 Profiles of metal concentrations for Al, Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn in Isadore's Lake, expressed as μg/g (left). Profiles of Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn normalized to Al in Isadore's Lake expressed as the ratio of each metal's concentration to Al concentration (right). A vertical line shows the ISQG concentration for As, 7.24 μg/g.

5.3.3 Shipyard Lake

Grain size distribution

The sand content of the core S1 from Shipyard Lake (Figure 5.18) core ranged from 40-60%, with an average of 53%. A sand lens (60-99% sand) occurring between 16– 20 cm depth suggests a particularly strong flooding event by the Athabasca River. Clay content averaged 35% for the entire core, but periodic increases in clay content in the upper 10 cm of the core increased the average above 10% to 45.6%. Silts comprised 1-4% above 10 cm, with an average content of 15 % throughout the whole core. A small peak in silt content (25 – 49%) was present at 10 – 12 cm depth. From 35 cm depth to the bottom of the core at 40 cm depth, %silt increases to an average of 29.1%.

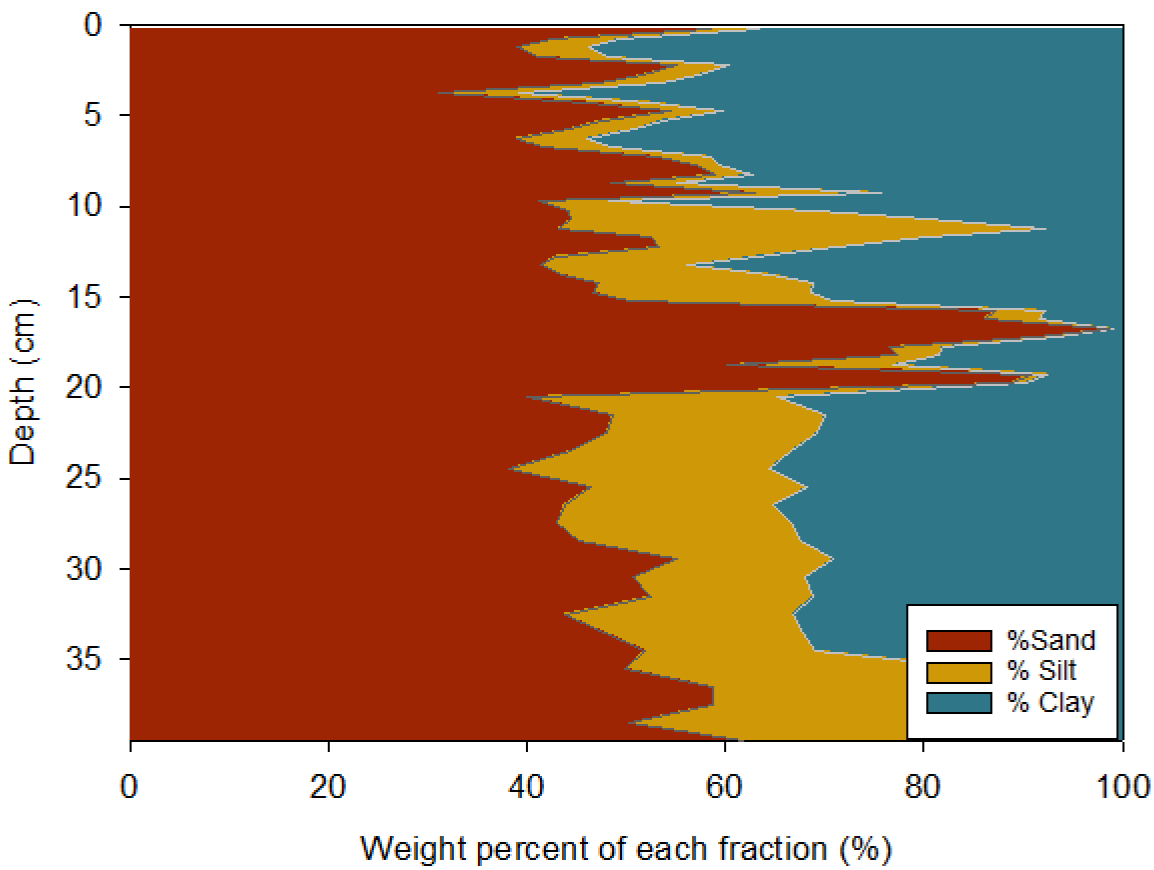


Figure 5.18 Particle size distribution of sediment core S1 from Shipyard Lake.

Water content

All three cores taken from Shipyard Lake (S1, S2, and S3) showed a similar pattern of an irregular decrease in percent water content with depth (Figure 5.19). Both core S1 and S2 averaged 73% water content over the whole core, while core S3 was slightly lower at 68%. In cores 1 and 2, an abrupt decline occurred between 15-17 cm depth, while in core 3, the decline occurred at 10 cm depth. For core S1, this depth roughly corresponds to the appearance of the sand lens (Figure 5.18). Below 20 cm, water content did not decrease uniformly with depth; changes in water content with depth did not correspond to changes observed in particle size distribution for core S1 (Figure 5.18).

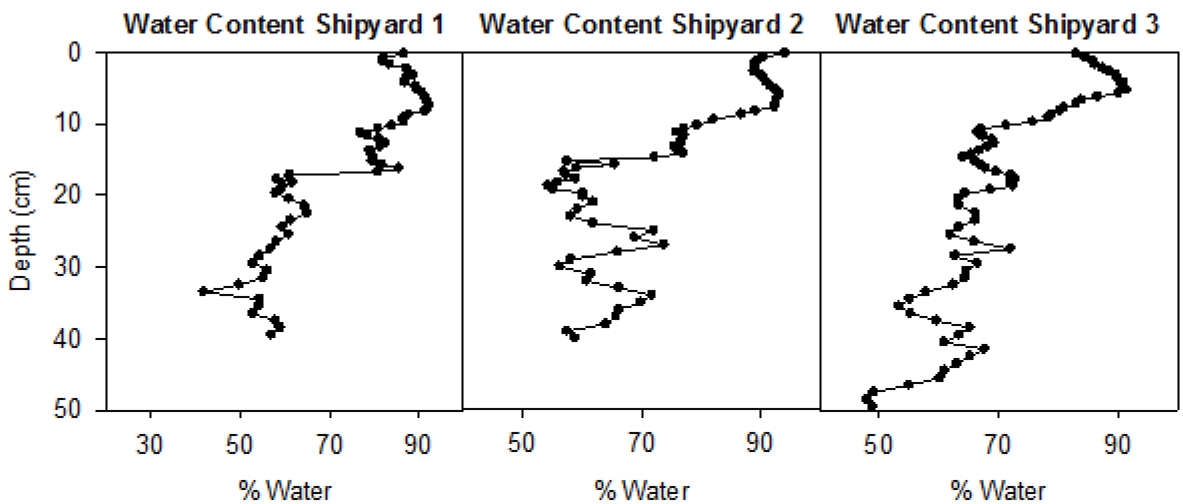


Figure 5.19 Water content by mass in each core taken from Shipyard Lake, expressed as %.

Magnetic susceptibility

Magnetic susceptibility measurements show major differences in magnitude between different cores (S1, S2, and S3) in Shipyard Lake (Figure 5.20). Higher variability in magnetic susceptibility was observed in S3, which varied from 1.49 – 31.9 x10^{-8} m^3/kg, while S1 ranged from 1.45 – 9.52 x10^{-8} m^3/kg and S2 ranged from 1.22 – 16.53 x10^{-8} m^3/kg. Strong correlation between cores S2 and S3 can be observed, with peaks in measurement occurring at 7-8 cm and 14-15 cm depth. On the other hand, the shallower peak was observed at a different depth in core

S1, at 5-6 cm depth, while the deeper peak was not observed at all. Background measurements in Shipyard Lake appear highly stable below 12-15 cm depth.

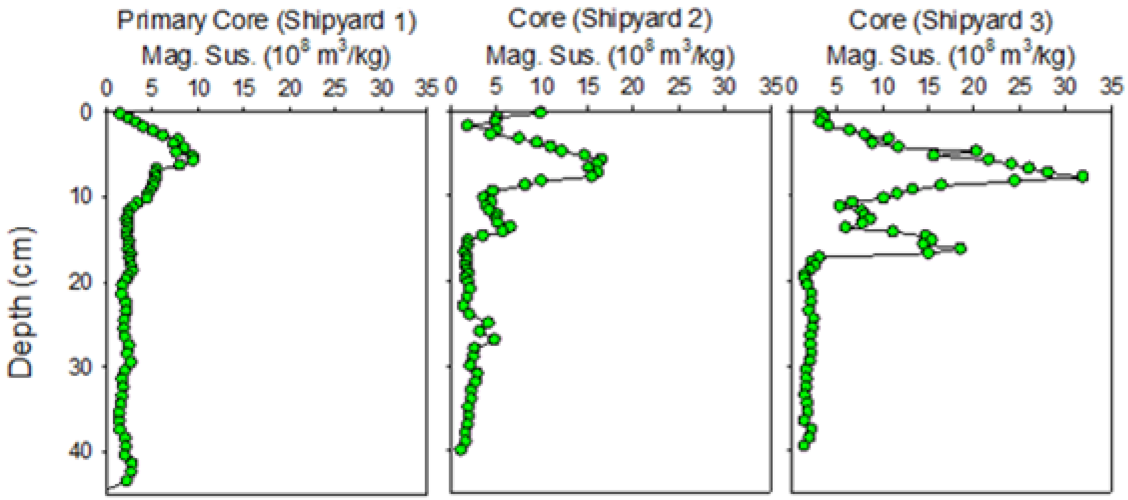


Figure 5.20 Magnetic susceptibility in each core taken from Shipyard Lake, expressed as 10^{-8} m^3/kg.

Dating

Surface Pb-210 concentrations for Shipyard core S1 are extremely low (< 100 Bq kg^{-1}) and increased from the top of the core down to 5 cm (Figure 5.21). This corresponds to the depth at which magnetic susceptibility begins to decline (Figure 5.20). From 4 cm depth downwards (212 Bq kg^{-1}) it follows a more conventional decay curve, and approaches background levels at ~12 cm depth. At 13 cm depth there is a slight increase in unsupported Pb-210 activity.

Peak Cs-137 activity occurred at 9.75 cm midpoint depth, which corresponds to the CRS-derived date of 1947 ± 15 years (Figure 5.21). This peak in Cs-137 activity falls outside of error for the 1963 Pb-210 date. The Cs-137 peak in Shipyard S1 appears flattened. Following this peak, Cs-137 declines sharply, until a secondary peak at 3.5 cm is observed.

Based on the unconventional decay curve of Pb-210 and the flattening of the CS-137 activity profile is likely that the age models is invalid. Due to the issues with the age models determined for Shipyard Lake, it was decided that dates would not be used, and subsequent analyses would be judged solely using depth.

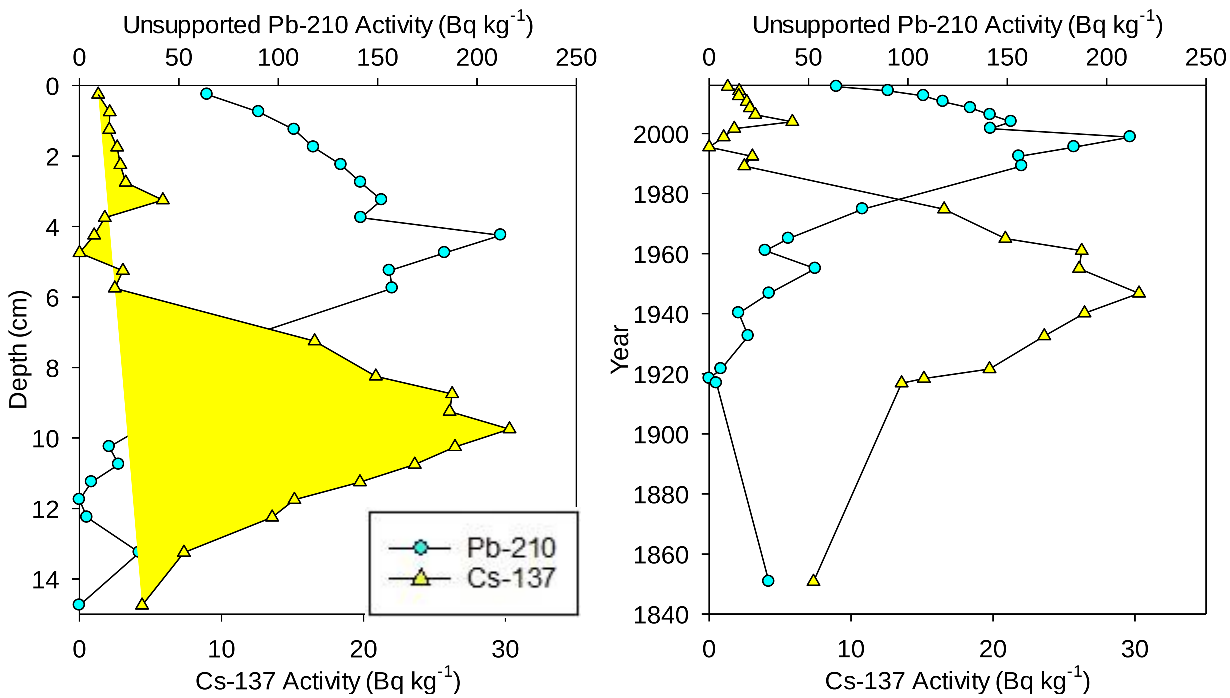


Figure 5.21 Profiles of Pb-210 and Cs-137 for Shipyard Lake.

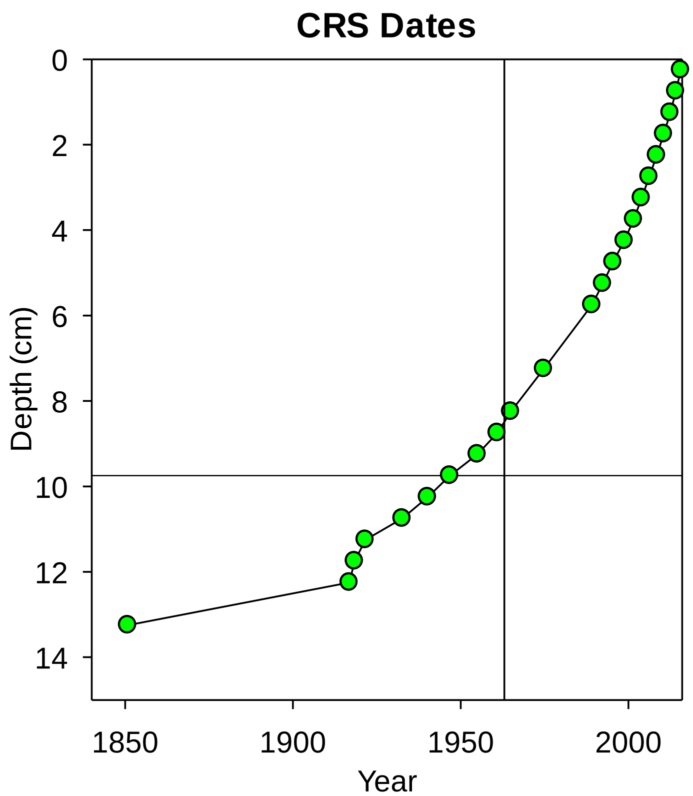


Figure 5.22 CRS model results for Shipyard Lake. Horizontal line indicates depth of Cs-137 peak, and vertical line indicates CRS date of 1963.

Metals

In core S1 of Shipyard Lake, several metals demonstrated decreasing concentrations above 10 cm, particularly Al, Fe, Ni, V, and Zn, while Ca concentrations showed a pronounced increase (Figure 5.23). A peak in the concentrations of both Fe and Mn is observed from 4 – 5 cm in this recent period, Fe reaching 37418 µg/g and Mn reaching 441 µg/g, although an earlier peak in Mn from 26 – 27 cm depth at 573 µg/g was also observed. The metals Al, As, Cu, Pb, Mn, Ni, and Zn occurred in higher concentrations at depths greater than 20 cm than in the upper 10 cm of the core. ISQG guidelines for As were not exceeded in the upper 10 cm of the core as was observed in Isadore's Lake core I1 (Figure 5.17).

In Shipyard Lake, aside from mercury, Al normalized data followed the same temporal patterns as the unadjusted metal data. The rise in metal concentrations is much more immediate as compared to what was observed in NE20, with V/Al rapidly increasing from 259 x10^6 to ~534 x 10^6 between 14.75 – 13.75 cm. Within the core S1, V/Al never returns to pre-disturbance levels (Fig 5.23). A small decline in enrichment is seen before a peak at 5.75 cm. A matching signal is seen for Ni/Al, in Shipyard; albeit less well pronounced. This shows enrichment from 303.6 x10^6 to 532.2 x10^6. Coinciding with the onset of these abrupt rises is the beginning of a positive trend in Ca/Al.

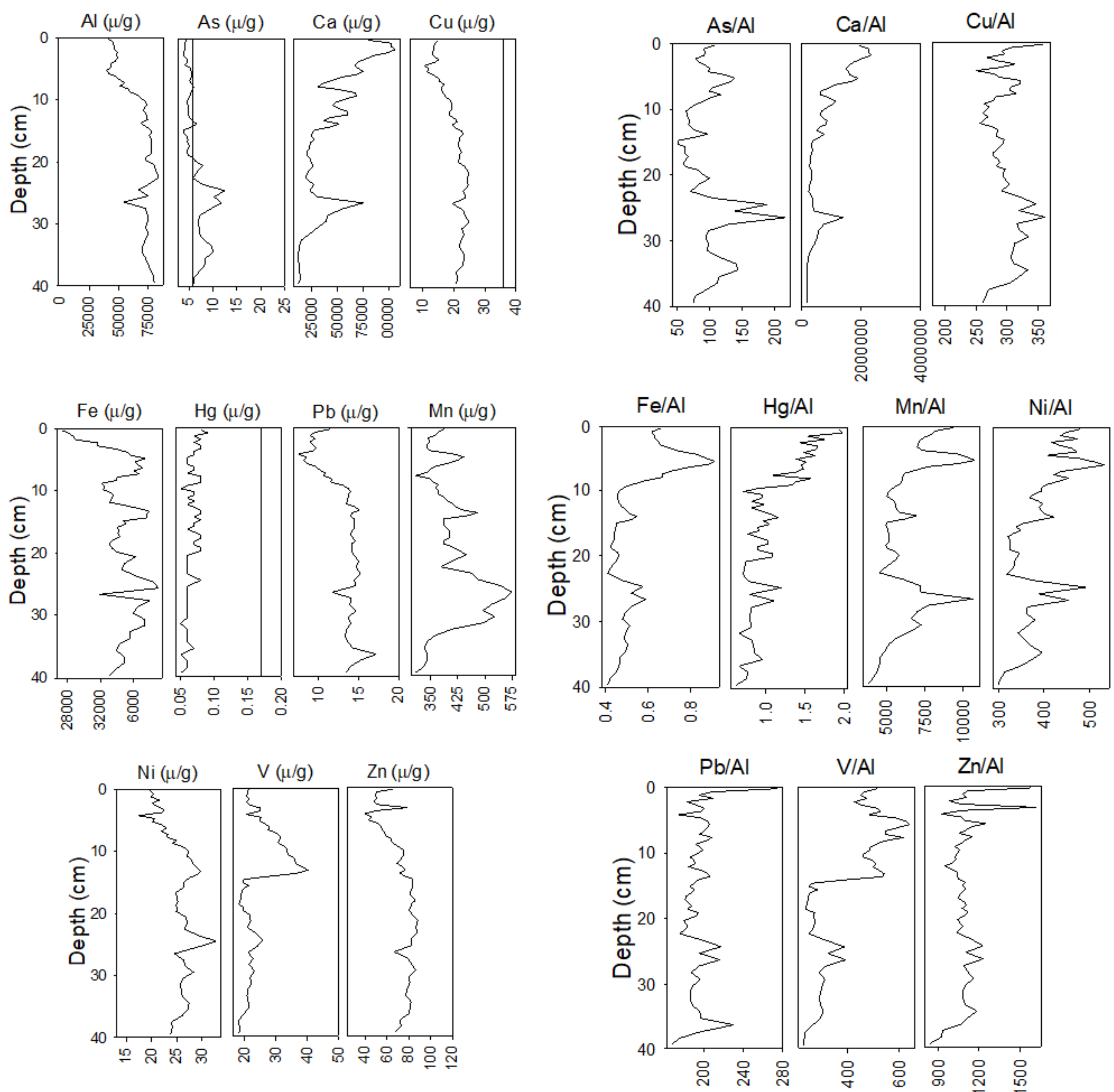


Figure 5.23 Profiles of metal concentrations for Al, Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn in Shipyard Lake, expressed as µg/g (left). Profiles of Ca, Fe, Mn, As, Cu, Hg, Pb, Ni, V, and Zn normalized to Al in Shipyard Lake expressed as the ratio of each metal's concentration to Al concentration (right). A vertical line shows the ISQG concentration for As, 7.24 µg/g.

5.3.4 Carbon, nitrogen, and chlorophyll

The mean organic carbon content of NE20 was 27.1%, which is extremely high and reflective of high primary productivity within the lake (Nara et al., 2005). In Isadore's Lake, mean total carbon content was 5.12%, mean Chl α was 0.014 mg/g, and mean total nitrogen was 0.35%. In Shipyard Lake, mean total carbon was 10.25%, mean Chl α was 0.0087 mg/g, and mean total nitrogen was 0.69%. Initial analyses were conducted on these variables, but as no significant trends were observed and they were not considered critical to this thesis, they were not investigated further. Profiles for these carbon, nitrogen, and chlorophyll can be found in Appendix A, and the data for these variables found in Appendix B.

5.3.5 Enrichment factors

The degree of enrichment in each lake at peak concentration, as compared to background concentrations, varied between lakes, but some patterns were observed (Table 5.6). All three lakes showed significant enrichment in V, with NE20 showing the highest degree of enrichment, followed by Shipyard Lake and Isadore's Lake. This pattern matches what is seen for Pb, albeit with insignificant enrichment in Isadore's and Shipyard. On the other hand, both As and Ca were most enriched in Isadore's Lake, followed by Shipyard Lake, although Shipyard Lake showed no significant enrichment in As, and NE20 showing a net depletion in these metals. The last metal with notable enrichment is Hg, which fits neither of the previous patterns; NE20 is the most enriched, followed by Isadore's Lake and Shipyard Lake.

Table 5.6 Sediment Enrichment Ratios for peak enrichment of metals in each lake. Value corresponds to percent by which it has increased or decreased.

Metal	**Isadore's**	**Shipyard**	**NE20**
As	2.31	0.00	-0.24
Ca	5.32	2.63	-0.85
Cd	0.02	0.23	-0.33
Cu	-0.15	0.06	-0.27
Fe	1.43	0.20	1.49
Hg	0.89	0.48	1.13
Mn	0.64	0.48	0.15
Ni	0.29	0.33	-0.48
Pb	0.05	0.12	4.26
V	0.84	1.29	13.64
Zn	-0.06	0.14	-0.43

Both pre- and post-development metal concentrations in NE20 are lower than those seen in the floodplain lakes with the exceptions of Ca, which is much greater, and Hg, for which the post-development concentration approximately equal to that in the floodplain lakes (Figure 5.24, Figure 5.25). To assess pre- and post- oil sands development in Shipyard Lake and Isadore's Lake, depths representing the timing of the onset of oil sands mining operations were assumed based on the depth at which V and As present similar increases as was observed in NE20. This was deemed to be 10 cm depth in Shipyard Lake and 16 cm in Isadore's Lake. For Shipyard Lake and Isadore's Lakes, most metals occurred in similar average concentrations in the pre- and post-development period while for NE20, several metals including Fe, Mn, Hg, Pb, Mn, and V occurred in higher concentrations in the post development period. This is particularly apparent when observing the metal concentrations normalized to Al (Figure 5.25). These data can be examined more closely by looking at the detailed sediment core profiles (Figure 5.11, Figure 5.17, and Figure 5.23).

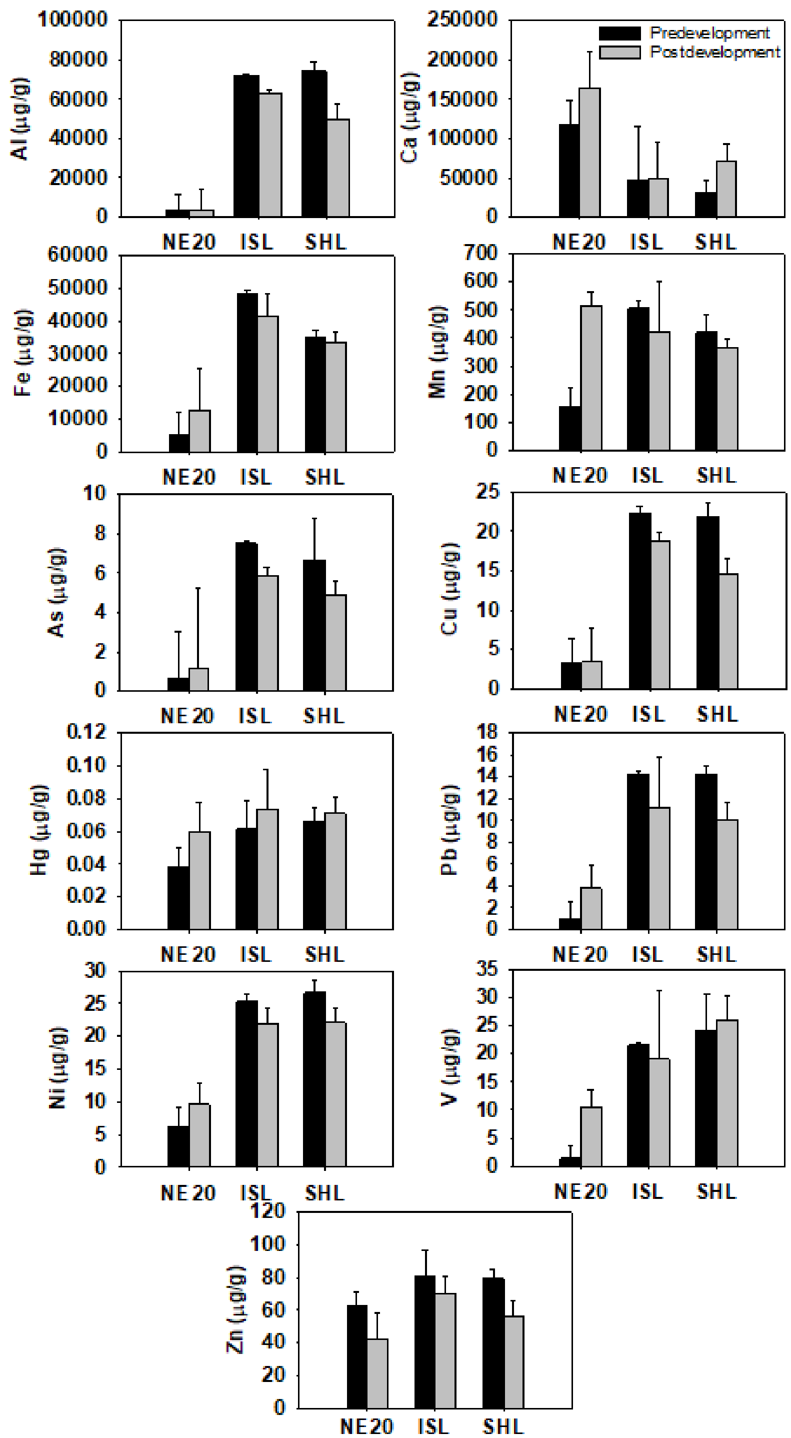


Figure 5.24 Average concentration of metals in each lake separated into pre- and post-development groups, presented as µg/g.

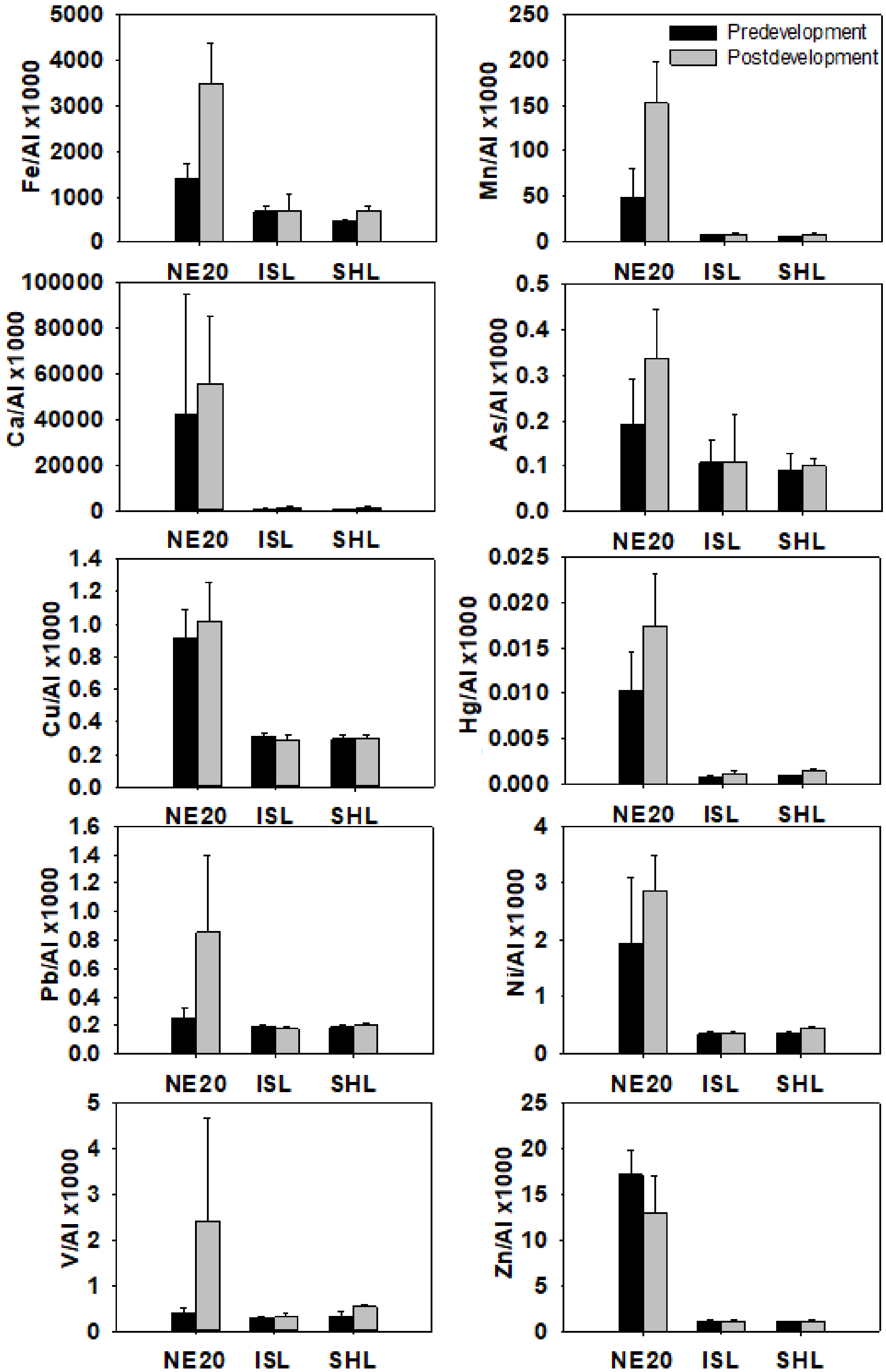


Figure 5.25 Average concentration of metals in each lake normalized to Al separated into pre- and post-development groups, multiplied by 1000 for clarity.

5.3.6 Comparison to lake sediment metal concentrations measured by previous studies

Concentrations of Al in P-NE20 of NE20 used in the present study were higher than what was reported for NE20 in Cooke et al. (2017). Fe and Mn concentrations, however, were found to be higher in the Cooke et al. (2017) study. For the other metals considered in the present study (As, Cu, Hg, Pb, Ni, V, and Zn) concentrations were similar to what was reported by Cooke et al. (2017).

Metal concentrations for metals on which a total digestion procedure was performed in the present study, Al, Fe, Mn, Ca, Cu, Cr, Ni, Pb, V, and Zn, for both Isadore's Lake and Shipyard Lake were greater in the present study than those measured by RAMP, except for Ca in Isadore's Lake (Table 5.7). As per the concentrations determined from the partial digestion procedure performed in the present study, only As and V were found to be in higher concentration in the RAMP data, while Hg was relatively enriched in the present study.

Table 5.7 Ratio of metal concentrations measured in the present study to those measured in previous studies. Metal partitions in bold were used in the present study for evaluation of trends.

Comparison source	RAMP	RAMP	Cooke et. Al
Lake	Isadore's	Shipyard	NE20
Metal			
Al (total digestion)	6.87	5.59	7.23
Fe (total digestion)	1.63	1.33	0.36
Mn (total digestion)	0.92	1.09	0.62
Ca (total digestion)	0.34	2.50	1.64
Cu (total digestion)	1.52	1.16	1.58
Cr (total digestion)	4.09	3.05	6.23
Ni (total digestion)	1.64	1.41	3.38
Pb (total digestion)	1.83	1.29	3.15
V (total digestion)	4.53	2.45	2.34
Zn (total digestion)	1.50	1.27	1.39
As (partial digestion)	0.51	0.62	1.29
Cu (partial digestion)	1.18	0.83	1.10
Hg (partial digestion)	1.88	1.57	0.89
Pb (partial digestion)	0.98	0.83	2.47
Ni (partial digestion)	1.36	1.06	1.33
V (partial digestion)	0.69	0.54	1.20
Zn (partial digestion)	1.13	0.96	1.24

5.4 Interpretation of results

5.4.1 Contributing factors to changes in lake area

This research demonstrated that, while there has been no notable change in the position of the floodplain lakes relative to the Athabasca River since the beginning of the aerial photograph record, there appears to have been a significant increase in the area of both Shipyard and Isadore's Lake since 1984. This channel stability seems counter-intuitive to what has been observed in similar situations, in which increased evapotranspiration due to increased mean temperatures has reduced the volume of lakes, as well as the shifts in channel position that are predicted to occur in the downstream Peace-Athabasca delta as a response to dam construction and climate change (Schindler and Donahue, 2006). In the short term, the increases in lake area reasonably fit with climate predictions for the region (Toth et al., 2006), as well as observations from lakes similarly fed by glacial meltwater (Liao et al., 2013). As these increases in lake area have only been observed for a relatively short period of time in recent years, the increased areas of Shipyard Lake and Isadore's Lake do not necessarily conflict with predictions for future flood levels in the region (Beltaos et al., 2006a; Prowse and Conly, 1998; Rokaya et al., 2017), in which ice jam flooding is predicted to grow less frequent and have reduced ability to recharge floodplain lakes.

The correlations present between the weather variables analysed in this study and the surface area of Isadore's Lake and Shipyard Lake may suggest that evaporation plays a larger role than precipitation in determining lake area The trend of a temperature increase, as well as the absence of trends in precipitation, is similar to findings reported for other North American high-latitude environments (Keyser et al., 2000). Groundwater constituting a key factor in determining the input to Isadore's Lake corresponds to the highly variable groundwater input that was reported for Isadore's Lake in a previous study (Albian Sands Energy Inc. 2005). This increase in area is consistent with contemporary measurements of Isadore's Lake area and was observed in aerial photographs regardless of season. Isadore's Lake in May 1972 shows similar area to present day, but this was following a year of extreme snowfall, which could have filled the lake more than what was observed in other years prior to 1994. It is possible that the lake area is less determined by mean trends in these climatic factors, than it is by recent flooding events inundating the lake or increased water retention due to beaver dams, as may occur in Shipyard Lake, or increased groundwater input, in the case of Isadore's.

The water level (m) at HYDAT 07DA001 was found to be insignificant to the lake area. Water level was typically highest from April to July throughout the period for which data was collected. This is expected, as the hydrology of the region is sustained largely by spring meltwater (Peters and Prowse, 2006; Pietroniro et al., 2006). Between 1998 and 2010, there was a continuous period of low mean monthly water levels (Fig 5.2), which stands in contrast to what is seen in the lake areas, which were consistently large during that time.

Conductivity in Shipyard and Isadore's Lake has not changed over the course of the RAMP study, which may suggest that no change in groundwater input has occurred since these lakes were sampled from in 2001 (Hatfield Consultants et al., 2016a). If there was an increasing volume of groundwater input to Shipyard Lake resulting in its expansion, the conductivity of Shipyard Lake water would reflect the conductivity of local groundwater (Engelbrecht et al., 2004). Since no change in conductivity was reported, it seems unlikely that an increasing volume of groundwater input is responsible for the increase in lake area.

Since the area of each of the floodplain lakes appears to have significantly increased over the past 30 years, with no corresponding increase in precipitation or water level, and likely no increase in groundwater input, an alternative explanation is required. Increased input from Mills Creek and other input channels is a possibility, though without a corresponding increase in precipitation to fuel an increased flow volume, this seems unlikely. It is more likely that this is not an actual increase in area in the lakes. Visual identification of submerged vegetation is prone to error, and so this perceived increase in area could be caused by difficulties identifying the dieback of emergent vegetation due to increased chlorophyll concentrations and shading due to unknown deposition influences (Macomber and Fenwick, 1979; Marshall and Lee, 1994). Alternatively, macrophytes at the edges of the lakes, particularly Shipyard Lake, could make differentiating between wetted ground and the actual lake body difficult. Macrophytes can be seen prominently in Shipyard Lake (Figure 3.5). The presence of macrophytes influencing interpretation of lake area would not explain the change in Isadore's Lake area, and only applies to the more recent increases in Shipyard Lake area. The most probable cause, then, is that this perceived increase in lake area is due to the frequency of image capture; substantial seasonal variation in water level could lead to images depicting a seasonally swollen lake as the most common lake size. Since these are small lakes, it is also possible that recent precipitation events have filled them beyond average volume (Crétaux et al., 2011). A final alternative explanation could be beaver dams limiting the loss of water from these lakes. It is understood that Shipyard Lake is influenced by a beaver dam, so this is likely a contributing factor (Golder Associates Ltd., 1996).

5.4.2 Flooding and depositional history

To link the flood history of two floodplain lakes, Shipyard and Isadore's Lake, to the deposition of metals, the down-core particle size distribution of lake cores was analyzed, which were compared to the particle size distribution of an upland lake, NE20. It has been established in environmental baseline studies that Shipyard Lake is flood prone (Golder Associates Ltd., 1996), while Isadore's Lake should be infrequently flooded (Inc., 2005). Sand lenses were found in both floodplain lakes, at different depths; these may signify major floods that have occurred, depositing significant sand and potentially removing previously deposited sediment.

The observed flood frequency in Shipyard Lake based on water levels at HYDAT 07DA001 matches closely to what was reported in the environmental baseline study conducted on this lake (Golder Associates Ltd., 1996). Particle size analysis of Shipyard Lake sediments corresponds with this, as well, with frequent, brief increases in sand content. These frequent, brief increases in sand content are similar to what has been seen in other low-lying floodplain lakes that are subject to frequent open-water flooding (Baldwin and Mitchell, 2000; Bohacs et al., 2000; Marsh et al., 1999). Since neither flood frequency nor sedimentation have demonstrated changes since the beginning of their periods of observation, it can be inferred that Shipyard Lake continues to receive sediment from the same sources as it has since observation began.

Previous studies in Isadore's Lake examining surface sediments found that sand content was low averaging 12.8 ± 11% (Evans et al., 2016). These collections, made under RAMP using a zodiac where boat passage may have been limited by aquatic weeds, may have been made in other sections of the lake whereas the core used in the present study was collected in a depositional area of the lake. Since Isadore's Lake is infrequently flooded by the Athabasca River, the sands must originate from erosion from within the watershed including sands deposited during periodic flood events. The deposition of both clays and sands imply some seasonality to deposition in Isadore's Lake, as high precipitation seasons could introduce sand eroded from the banks and nearby hills, while a calmer season could allow fallout of fine clay particles. Taking the previously reported flood frequency of Isadore's Lake (Albian Sands Energy Inc., 2005) together with what was determined from the water level records in the present study, it would be expected that Isadore's Lake should receive significant input of sand-sized particles only during 20-year flood events and above, which may explain the observed sand lenses.

It is possible that, taking the local topography into account, that there has been erosion from the nearby hills or scouring of the streams that feed Isadore Lake. In either case, an incision into the strata following heavy precipitation events could reveal sandy material that has not been exposed to the surface since the oil sands development began, which would allow a precipitation event to erode metal-poor material into the lake. Erosion and subsequent deposition of metal-poor sandy material could explain both the presence of a sand lens in Isadore's Lake as well as the difference in Pb-210 activity between Shipyard and Isadore's. Since Shipyard experiences open-water flooding, sand deposition could occur without a corresponding decline in Pb-210 inventory and metal content. It is alternatively possible for Shipyard Lake that strong wave action resuspends fine sediments, which become deposited in shallower areas due to macrophyte trapping, rather than in the deeper sections.

5.4.3 Spatial heterogeneity in floodplain lakes

Comparison of metal concentrations between those measured in the present study and those measured by RAMP was difficult due to differences in digestion procedures used. RAMP only performed a total digestion by aqua regia (a mixture of nitric and hydrochloric acids) procedure, which does not allow the labile fraction of metals to be observed, nor does it fully digest refractory metals such as Al, Fe, and Ca (Hatfield Consultants et al., 2016b). Similarly, all metals measured by Cooke et al. (2017) were subjected to partial digestion by HNO3 and HCl so as to target only metals within the labile fraction of the sample and not those bound within mineral lattices.

Considering the lakes as individual basins, it appears that, within each, there is a degree of spatial heterogeneity. Spatial heterogeneity in NE20 is showcased by the difference in magnitude and timing of deposition for metals taken by other recent coring studies (Cooke et al., 2017) (Figure 5.11, Table 5.7), as well as differences in water content between P-NE20 and C-NE20 (Figure 5.8). In NE20, enrichment begins above 5 cm depth for As, Cd, Cu, Hg, Pb, and V, returning to background levels for all metals except Pb, and V. Concentration of V is declining similarly to what was shown in other recent studies (Cooke et al., 2017), though they show an earlier peak in V concentration between 1971-1976 and more rapid return to background levels. Average concentration of V within the top 1 cm of sediment for cores collected by this study is 31.2 μg/g, while that observed in the Cooke et al. (2017) study was 18.5 μg/g. This difference may be influenced by this studies' cores being collected more recently. Within the top 5 cm of sediment, the concentration of Hg measured by this study is significantly lower than that measured in the by Cooke et al. (2017) though this is due to a pocket of low Hg concentration between 3-5 cm depth; the difference disappears when only the upper 3 cm is considered.

It is additionally possible that the differences in sediment dates observed between those modelled in the present study and the dates modelled in Cooke et al. (2017) represent sediment focussing in NE20, as well as the mobilization of some metals. This may be indicated by the water content variation in NE20 between P-NE20 and C-NE20 (Figure 5.8), which could have represented movement of water in the sediment column, or the preferential deposition of sediment based on lake morphometry. The migration of 137-Cs has been previously observed to affect the validity of age models (Klaminder et al., 2012; Medeiros et al., 2014). It is possible that 137-Cs has migrated along with the potentially mobile Fe and Mn, which may be represented by the secondary peaks observed for Fe and Mn concentration (Figure 5.11) as well as the minor flattening of 137-Cs activity (Figure 5.9). This suggests that even under ideal depositional conditions, as are observed in NE20, metal mobility and sediment focussing can affect the reliability of dating.

In both Shipyard Lake and Isadore's Lake, magnetic susceptibility measurements (Figure 5.14, Figure 5.20) show marked differences in magnitude in cores located < 10 m apart. Similar instances of spatial heterogeneity in the geochemistry of floodplain lakes have been previously documented by van Griethuysena et al. (2003) for the Waal River in The Netherlands, in which the availability of metals was found to vary strongly with regards to depth, redox potential, and total sulfur found in different sections of lakes. If there are similar spatial aspects to the availability of toxic metals here, then it is possible that studies sampling from these lakes are limited in their ability to make conclusions with regards to the whole lake if their sampling area was limited in scope. Additionally, comparison between studies, even when conducted on the same lake, would be difficult to make if large variations in physical and chemical parameters can be present across small areas of lake beds.

5.4.4 Metal concentration in recent sediments of floodplain lakes

NE20

Overall, none of the recent concentrations of toxic metals in any of the study lakes are sufficiently high to conclude that adverse impacts will be observed. Taking NE20 as an example of what would be expected from an ideal depositional environment in this region, the input of metal derived from oil sands mining and bitumen upgrading has declined since the onset of oil sands mining, particularly with respect to the atmospheric transportation of metal (Shotyk et al., 2017; Shotyk et al., 2014).

While the non-normalized concentrations of metals such as As, Fe, Mn, Ni, and V seem to suggest that they are enriched in recent sediment, when considering the deposition of clay represented by normalizing to Al, they have each either returned to background or are trending towards background concentration in NE20. This sequence of metal concentration changes suggests that, following a period of enrichment that may coincide with the early development of the oil sands in the 1960s (Oil Sands Discovery Center, 2016), there was enrichment of metals in NE20 provided by the atmospheric transport of metal-bearing dust and upgrader emissions. Following this enrichment, there is a peak in the normalized concentration of these metal concentrations for As, Fe, Hg, and V, each of which subsequently returned or are returning to background concentration.

Their return to background concentrations may correspond to the installation of hydrostatic precipitators to control upgrader emissions as was suggested by Cooke et al. (2017). On the other hand, some differences were observed between the primary core and the core analyzed by Cooke et al. (2017), such as the continued enrichment in Pb in the primary core, which was observed to have begun to decline in the core taken by Cooke et al. (2017). Despite these differences, NE20 represents the typical profile of metal deposition expected in undisturbed lakes in the Athabasca region.

Isadore's Lake

In Isadore's Lake, a brief increase in the Al-normalized concentration of As, Ca, Fe, Hg, Mn, Ni, and V occurs following above 15 cm depth. All metals that became enriched during this period from 15 – 10 cm depth rapidly returned to background concentration. Of these, only Hg demonstrated subsequent enrichment above background concentration, which may be linked to global trends in Hg emissions (Fitzgerald et al., 1998). Since Isadore's does not receive direct flood input from the Athabasca River (Inc., 2005), and the adjacent Albian Sands tailings pond did not exist at this time to possibly release metals to groundwater (Oil Sands Discovery Center, 2016), it can be assumed that these metals were provided by atmospheric transport of dust and upgrader emissions from the early oil sands development, which have since been controlled more rigorously (Shotyk et al., 2017; Shotyk et al., 2014). On the other hand, other groundwater sources may have contributed to this enrichment.

It is possible that a large amount of sediment containing low metal concentrations was deposited into the lake sometime after this period of enrichment from 15 – 10 cm depth, possibly through the scouring of one or more channels that feed Isadore's Lake. A likely depth for this deposition event would be 5 – 10 cm, at which a well-defined sand lens (Figure 5.12), a decline in water content (Figure 5.13), an increase in magnetic material based on magnetic susceptibility measurements (Figure 5.14), and a steep decline in Pb-210 activity (Figure 5.15) is observed. This would suggest that the expected profile of metals deposition due to atmospheric deposition, similar to what was observed in NE20, was observed in Isadore's Lake, as well, but appears much deeper in the Isadore's Lake core than in NE20 due to this deposition event.

For the majority of the core, the ISQG guideline was surpassed for As in Isadore's Lake (Figure 5.17), which implies that the baseline As concentration within the lake, in the absence of industrial development, is above the guideline (CCME, 1995; Hatfield Consultants et al., 2016a). Al adjusted data showed similar temporal patterns. Following the period of enrichment observed from 15 – 10 cm depth, neither As nor V rise above background concentration for the remainder of the core. This response most closely resembles the trends in metals detected in other industrialized regions (Arnason and Fletcher, 2003).

Increasing trends in %alkylated PAHs, C_1-C_4phenanthrenes/anthracenes, and ΣDBTs from 2001 – 2014 as reported by Evans et al. (2016) in Isadore's Lake and by Kurek et al. (2013) in lakes throughout the Athabasca Region may imply that, while the controls in place for metals are effective, hydrocarbons are still being released into the environment.

Shipyard Lake

Metal deposition in Shipyard Lake is more complicated to interpret than in Isadore's Lake or NE20. A distinct enrichment of V and Ni beginning well before the assumed post-development period based on enrichment of V and As was observed, and the post-development enrichment in these metals was observed to be much more muted. Unlike in NE20 and Isadore's Lake, normalized concentrations of Fe, Mn, Ni, and V have not returned to background concentrations (Figure 5.23). This lack of return to background conditions may correspond to the much greater concentrations of ΣPAH in Shipyard Lake compared to other Athabasca Region lakes as reported by Evans et al. (2016), and may imply that Shipyard Lake continues to receive these metals in excess of what would be expected based on the deposition of clay minerals.

Shipyard Lake is much closer to the older, original development sites of the GCOS and Suncor, at which there may be more exposed or available bitumen deposits from which eroded material could more easily be deposited in low-lying Shipyard Lake than the more elevated lakes. While it has been well-established by studies such as Kelly et al. (2010) and Kelly et al. (2009) that natural bitumen erosion is unlikely to be responsible for the enrichment in PAHs in lakes of the Athabasca Region, it seems possible that any continued enrichment of metals in low-lying floodplain lakes may be related to such natural erosion.

Due to the low elevation of Shipyard Lake, it seems possible that flooding has disturbed and redistributed sediment, making the determination of a clear oil sands signal impossible. The difficulties presented by Shipyard Lake with regards to the history of metal deposition due to metal remobilization through flooding has been previously suggested by Hall et al. (2012), and is reflective of the dynamic nature of the Athabasca River floodplain.

5.4.5 Limitations

There are serious limitations in the approach of the geomorphology component of this study, which limit its interpretive power. First, the aerial photographs of each of the floodplain lakes are few in number, and some of the images are not tied to exact dates. If an image cannot be tied to the weather and water level measurements on the date it was taken, as the date is unknown, little can be said about the relationship between lake area and these variables. Trends observed from the lake area inferred from these images, then, are not necessarily reliable. Furthermore, determination of area from these aerial photographs carries a degree of error, since the delineation between lake water, shrubbery, and shoreline was not always clear. Relative depth of water, additionally, could not be inferred from these images. Next, the water levels taken at 07DA001 do not directly correspond to water levels adjacent to Isadore's and Shipyard Lake; the channel morphology likely differs; increases in water level at the measurement station are not necessarily equal increases in water level at the lakes, as was assumed by this study. Similarly, the increase in water level relative to the mean water level required to flood each lake was inferred from topographic maps and previous reports; since the channels are dynamic, it is distinctly possible that this information does not hold true for the entirety of the HYDAT measurement period used for this study.

There are limitations to the approach of the sediment chemistry component of this study, which should be considered for future endeavors. To begin, this study only involved two floodplain lakes and one upland lake; the limited number of study sites limits the power of this study by increasing its vulnerability to these lakes not being representative of what may be seen in most lakes in this region. Additionally, these lakes are not spatially distant from one another, which increases the chance of bias. This limitation could be remedied be increasing the number of lakes under analysis to ascertain if what was observed for these lakes is true across a wider geographic area. Next, the assessment of guideline exceedances was based upon the CCME sediment quality guidelines, which were based on average lake sediment metal content and toxicological profiles, so may not be useful for assessing impacts in all settings. Future studies may incorporate EPA guidelines alongside CCME guidelines, comparing between systems and broadening the assessment. Additional analyses of metal speciation could provide further information as to the mobility and toxicity of metal indicators in these lakes, particularly As. Lastly, though they were explored as options during early stages of analysis, normalization to Li or Ti may offer further insight into the depositional history of these lakes that was not observable through Al normalization. Normalizing to any reference element can introduce bias due to variation in input of that element, so including multiple normalization factors could reduce error (Reimann and de Caritat, 2005).

6. Conclusions

6.1 Introduction

The objective of this thesis was to investigate the geomorphometric and geochemical changes in Athabasca River floodplain lakes that have occurred over the past century, thereby expanding our understanding of metal indicators as related to the Athabasca oil sands. This is accomplished by quantifying the frequency of flooding in two lakes on the Athabasca River floodplain near oil sands developments, Isadore’s Lake and Shipyard Lake, and determining if changes to their morphometry have occurred. To investigate the geochemical changes that occurred in these lakes, trace metal concentrations were analysed to observe trends in the deposition of metals in these lakes, as well as an upland lake located near the oil sands development, NE20. Overall, this thesis demonstrated the difficulty in establishing an accurate record of metal deposition in a dynamic environment such as a floodplain lake and expanded our understanding of how sediment quality in lakes is controlled by hydrologic factors such as flooding.

6.2 Floodplain lake morphometry

This study investigated the geomorphometric changes that have occurred in two lakes on the Athabasca River floodplain. The objective of this analysis was to assess changes in the geomorphometry since the early 1900s and relate those to flood events, to provide a framework with which to interpret changes in metal concentrations in these lakes. A key component of the framework of this analysis was the use of legacy data, specifically legacy aerial photographs, weather data, and hydrometric data, which has been analyzed using Geographic Information Systems (GIS) in combination with analysis of variance (ANOVA) to present a temporal perspective on changes occurring to the floodplain lake environment.

The key findings presented regarding floodplain lake morphometry relate to trends in weather variables in the Athabasca region, the flood frequency of Shipyard Lake and Isadore’s Lake as inferred from historic river levels and topographic data, and changes in lake area using georeferenced aerial photographs of Shipyard Lake and Isadore’s Lake. The only weather variable to significantly change during the period of data collection (1944 – 2007) was temperature (Figure 5.1), showing an average increase of 0.04˚C per year, which corresponds to changes found across the North American continent (Keyser et al., 2000). Flood frequency was found to have not significantly changed in either Shipyard Lake or Isadore's Lake throughout the period of water level data collection (1957 – 2012) (Figure 5.2). The area of both Shipyard Lake and Isadore's Lake significantly increased since the beginning of the aerial photograph record (1931 for Isadore's Lake, 1951 for Shipyard Lake) (Figure 5.3, Figure 5.5). This increase was observed to be particularly extreme beginning after 1984. These results show that, despite no corresponding changes in weather patterns or flood frequency, there has been a dramatic increase in the area of both Shipyard Lake and Isadore's Lake, though their position with respect to the Athabasca River remains unchanged.

6.3 Metals in lake sediment

Temporal changes occurring in the sediment of NE20, Shipyard Lake, and Isadore's Lake were analysed using the physical and chemical characteristics of sediment cores at different depths, and the concentration of environmentally relevant metals, which was linked to the timing of development of oil sands mining operations in the regions by Pb-210 dating.

The key findings presented in chapter 5 were the grain size analyses, the analysis of Pb-210 activity, and the changes and trends in the concentrations of As, Al, Ca, Cu, Fe, Hg, Mn, Pb, V, and Zn in each study lake. The analysis of metal concentrations showed that, despite an initial increase in the normalized metal concentrations of As, Ni, and V in each of the lakes following the onset of oil sands mining operations, there appears to be no recent enrichment of trace metals corresponding to the continuing expansion of operations (Figures 5.11, 5.17, and 5.23). The activity of Pb-210 in NE20 proved suitable for establishing an age model (Figure 5.9). The analysis of Pb-210 activity in Isadore's Lake and Shipyard Lake sediments, however, demonstrated that it was impossible to establish an age model for these lakes using Pb-210 due to irregularities in the activity of Pb-210 with respect to depth (Figure 5.15, Figure 5.21). The analysis of grain size distribution showed that Shipyard Lake and Isadore's Lake had generally higher sand content and more variability in grain size distribution as compared to that of NE20, implying dynamic depositional environments (Figures 5.7, 5.12, and 5.18). Together, these results imply that disturbances to sedimentation in floodplain lakes are an important factor affecting changes in metal concentrations, particularly with regards to flooding in Shipyard Lake.

6.4 The dynamic environment of floodplain lakes

Lakes that are subjected to disturbances in sedimentation will demonstrate irregular patterns of Pb-210 deposition, which will render dating impossible. Determining an age model from Pb-210 activity requires a continuous sediment record in which no removal of sediment, and thereby Pb-210, via erosion has occurred. Problematic dating was found for Shipyard Lake and Isadore’s Lake, each of which demonstrated disturbances to their sedimentation, but not for NE20, in which no major disturbances to sedimentation were detected.

The upland lake NE20 is more elevated than Shipyard Lake and Isadore’s Lake relative to the Athabasca River, and was not evaluated for flood frequency, as it should not occur. Since there was no possibility for river-attributed flooding in NE20, no disturbances to sedimentation were expected. Based on this expected continuity of deposition, it was expected that the Pb-210 profile of NE20 would present a clear record of deposition and allow accurate dating of the sediment cores taken from the lake, as was done by Cooke et al. (2017). In the present study, a clear record of deposition indeed allowed an accurate age model to be determined for NE20 (Figure 5.9). The curve of Pb-210 activity in NE20 represented an ideal curve, and enabled dating the core. As the only lake in the present study to exhibit such a limited amount of disturbance, NE20 also provided the only reliable age model.

Concerning Isadore’s Lake, no flooding was found to occur in the present study (Figure 5.2), and should not occur aside from 100-year flood events or ice jams (Inc., 2005). This resistance to flooding is due to the elevated banks surrounding Isadore’s Lake, which prevent flooding under most flooding events. The lack of open-water flooding in Isadore’s Lake might suggest a lack of disturbance resulting in a regular depositional history of Pb-210, but this was not the case. An irregular Pb-210 profile was found for Isadore’s Lake, featuring an early peak in Pb-210 activity at 11 cm depth, above which there is a trough in which activity decreases to near zero between 5-10 cm depth, and subsequently a second peak in activity at the surface (Figure 5.15). The trough in Pb-210 activity coincides with an abrupt decline in water content and an increase in sand content. As with Shipyard Lake, this implies a dilution of surface sediment in Isadore’s Lake. Due to the relatively higher elevation of Isadore’s Lake compared to Shipyard Lake, though, it is unlikely that this sand was supplied from the bed and banks of the Athabasca River. Rather, it is possible that this change in deposition was caused by the scouring of Mills Creek, the main tributary to Isadore’s Lake, or through erosion of the banks of Isadore’s Lake. A storm event could have resulted in the scouring of coarse-grained sediment from the creek bed or lake banks, which was redeposited in Isadore's Lake. Together, this suggests that even in the absence of flooding, it can be difficult to establish reliable histories for dynamic environments such as floodplain lakes.

In Shipyard Lake, flooding during the open water season was found to occur on a frequent basis in the present study based on HYDAT water level data (Figure 5.2), which agrees with what was reported in a previous environmental baseline study (Golder Associates Ltd., 1996). In Shipyard Lake, the activity of Pb-210 follows an irregular curve, as peak activity occurs at 5 cm below the surface and steadily declines above that point (Figure 5.21). This curve may represent flood-delivered sediment from the bed and banks of the main stem of the Athabasca River diluting the surface sediment of Shipyard Lake. This dilution of sediment may also be represented by the presence of multiple peaks in activity, both in Pb-210 and Cs-137. The dynamicity of the Shipyard Lake environment is further observed in both the particle size distribution, as a dramatic increase in sand content was observed from 16-20 cm depth. This dynamic environment, known to be prone to flooding, produced a Pb-210 activity profile that was functionally unusable.

6.5 Influence of flooding on metal accumulation in lakes

Metal accumulation in the study lakes parallels that which was observed in perched basins in the Slave River delta (Brock et al., 2007; Sokal et al., 2010) with regards to flooding and river connectivity affecting nutrient accumulation, with some key differences related to pathways. Of the three study lakes, NE20 does not experience river-based flooding, Isadore's Lake experiences infrequent river flooding, and Shipyard is frequently flooded by the Athabasca River. These differences in flood frequency have resulted in different dynamics for the accumulation of metals in each of the lakes.

Since NE20 is too elevated for the Athabasca River to flood it, it is not subjected to river-based influences on the accumulation of metals within it. Aside from the period of enrichment beginning at 6.75 cm depth and continuing to the surface, metal concentrations in NE20 were shown to be very stable and were of the lowest levels between the three study lakes. Since NE20 would receive primarily atmospheric deposition of metals, as well as some degree of metals from surficial runoff, this suggests that the lack of flooding in NE20 has exerted a strong control on the accumulation of metals in NE20. Metals are neither removed nor rapidly deposited by suddenly influxes of water and sediment from flooding, allowing a more stable depositional environment to exist. This is expected, based on what was observed regarding nutrient deposition in non-flooding rivers in the Slave River delta, in which non-flooded rivers were highly stable with regards to their chemical conditions.

Both Isadore's Lake and Shipyard Lake show depositional patterns that would be expected from flooding surfaces. This is particularly visible in Isadore's Lake, in which sequences of declining sediment grade can be seen; this is likely related to less frequent disturbances in this lake. If the primary source of metals is atmospheric, they would become sequestered in Isadore's Lake and buried within the sediment because of limited disturbances. If atmospheric transportation of metals had continued to recent times, this should be represented in Isadore's Lake sediments. Since it was established by Shotyk et al. (2014) and Shotyk et al. (2017) that the atmospheric transportation of metal pollutants has been insignificant since the 1980s due to the installation of hydrostatic precipitators, and elevated concentrations of metals in Isadore's Lake returned to background levels abruptly following initial enrichment, it is likely this is the case.

Metal concentrations in Isadore's Lake show the greatest variation in concentration between levels observed in the enrichment period from 12-14 cm depth and those observed at the baseline. This is similar to what is seen regarding nutrient accumulation in perched basins of the Slave River delta, in which infrequently flooded lakes showed the widest fluctuation in nutrient concentration depending on whether they were flooded or not. Since it is possible that Isadore's Lake was flooded in that period based on flood history analysis, if it represents a period of high atmospheric input of metals, it could serve a similar purpose. Outside of that period of enrichment, metal concentrations in Isadore's Lake are uniformly low, suggesting that in the absence of flooding or high atmospheric contribution, a naturally low baseline is observed. As with NE20, this further suggests that river flooding is a dominant factor in determining the accumulation of metals in floodplain lakes.

Conversely, in Shipyard Lake the increased throughflow could facilitate the remobilization and removal of metal-rich sediment, particularly if this remobilization occurs at flood stages, while supplying metal-poor sediment to the lake or introducing previously sequestered metal-rich sediment to the surface sediments. Similar remobilization of metals in sediment has been observed in both marine (Hunt and Smith, 1983) and river (Bordas and Bourg, 2001) sediments, and has been suggested to play a role with regards to PAHs in the Athabasca River floodplain (Hall et al., 2012). As Shipyard Lake is flood-prone, it is possible that variable concentrations of metals in recent sediments are due to a combination of the removal of metal-rich sediment from the lake and the focussing of metal-rich sediment into deeper areas of the lake. This interaction poses implications as to the vulnerability of floodplain lakes to metal accumulation, and how regular flooding may serve to flush recently deposited metals out of floodplain lakes and thereby protect them. The way that flooding controls metal concentration in flood-prone lakes differs from what was observed regarding nutrients in flood-prone lakes on the Slave River delta, in which frequently flooded lakes demonstrated stable nutrient concentrations. This may be due to the differences in sources of metals and nutrients, as metals will be primarily river-derived in the Athabasca region, whereas nutrients can be derived more from surficial runoff and atmospheric deposition.

6.6 Geomorphology

Shipyard Lake and Isadore's Lake appear to have dramatically increased in area, but there are no correlating factors that would explain this increase. As such, these increases in area must be assumed to be an artifact of the limitations of the data. No changes in the position of the lakes relative to the Athabasca River were detected. Isadore's Lake and Shipyard Lake have the potential to serve as records of metallic bitumen indicator deposition on the floodplain of the Athabasca River (Evans et al., 2016; Hatfield Consultants et al., 2016a). Disturbances to the lake beds via flooding, however, can reduce the effectiveness of investigating metallic bitumen indicator history through the lens of these lakes. In the absence of open-water flooding, changes to the input of groundwater must be considered, as this can serve as an additional vector of metal transportation. It is important that researchers of floodplain lakes consider the impact of changing lake morphology when considering sites for investigation. There is a need for further investigation into the effect of changing lake morphology on the ability for sediment to accumulate in floodplain lakes.

6.7 Sediment Chemistry

Overall, Isadore's Lake, Shipyard Lake, and NE20 show an increase in metal deposition, marked by a rapid increase in the normalized concentration of V. In Isadore's Lake, this increase appears to rapidly disappear, which, along with evidence from the activity of ^{210}Pb and particle size distribution, implies that infrequent, but extreme depositional events, such as slope collapse or channel scouring, led to the deposition of sand which lacked bitumen indicators. The potential impact of depositional events on the accumulation of metals in floodplain lakes carries broad implications for the analysis of metal concentrations in floodplain lakes, as such events may reduce the usefulness of results, and therefore must be considered. Additionally, differences in the metal concentrations reported by this study, and another recent coring study (Cooke et al., 2017), imply that spatial heterogeneity in small lakes may be an important factor when investigating metal accumulation; this implication is further supported by the inconsistent magnetic susceptibility measurements between cores in the two floodplain lakes. One must consider both the effects of spatial heterogeneity, as well as the potential influence of flooding, when investigating metal concentrations in small lakes. There is a need for further investigation into spatial differences in floodplain lake metal concentrations, and the factors that determine this.

6.8 Conclusion

The past century has seen exponential expansion of the oil sands industry in the Athabasca region, and significant effort has been made to ensure that environmental effects on the surrounding environment are limited. As part of this effort, this thesis investigated changes and trends that could be observed in the geomorphometry and trace metal composition of floodplain lakes and rivers adjacent to oil sands development. Due to the dynamic floodplain environment as determined through analysis of flooding and landform change, age models could not be developed for floodplain lakes to establish an accurate record of metal concentration. Additionally, recent trends and changes observed in the composition of metals in the sediment of floodplain lakes was found to parallel that in the water column of nearby rivers and streams, suggesting that both lake sediment and channel water columns are subject to the same input sources of metals in the Athabasca region.

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APPENDIX A

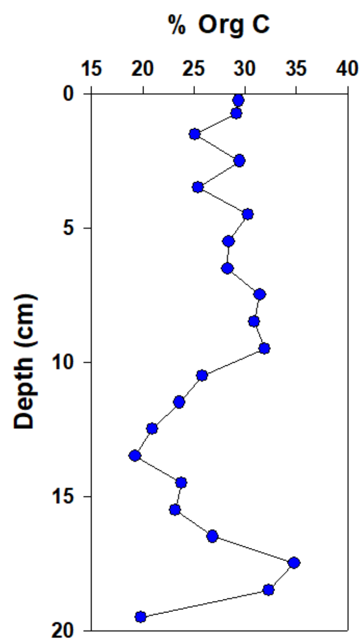

Figure A.1 Organic carbon content in NE20 expressed as % of mass of dry sediment.

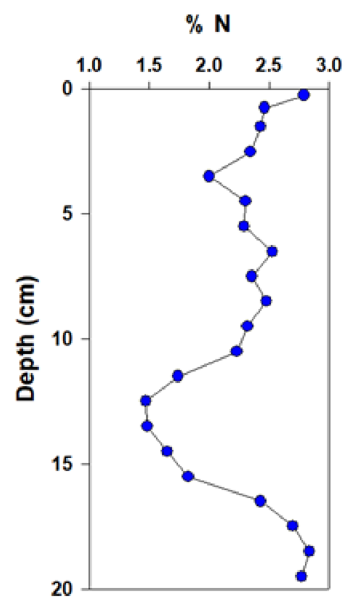

Figure A.2 Total nitrogen content in NE20 expressed as % of mass of dry sediment.

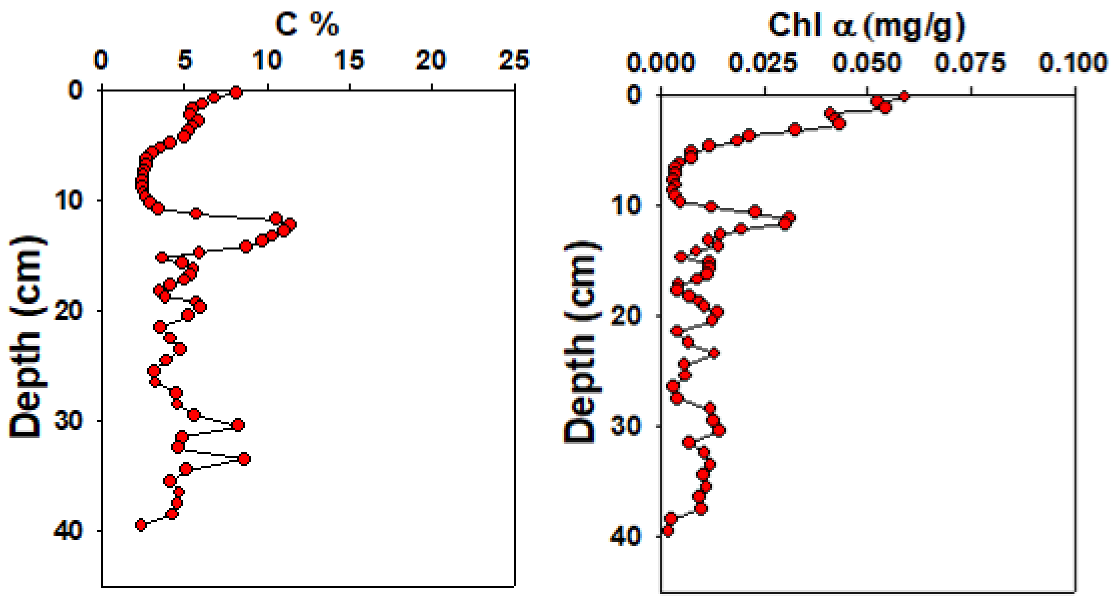

Figure A.3 Total carbon content expressed as weight % of sample mass for Isadore's Lake, and chlorophyll α counts expressed as mg/g for Isadore's Lake.

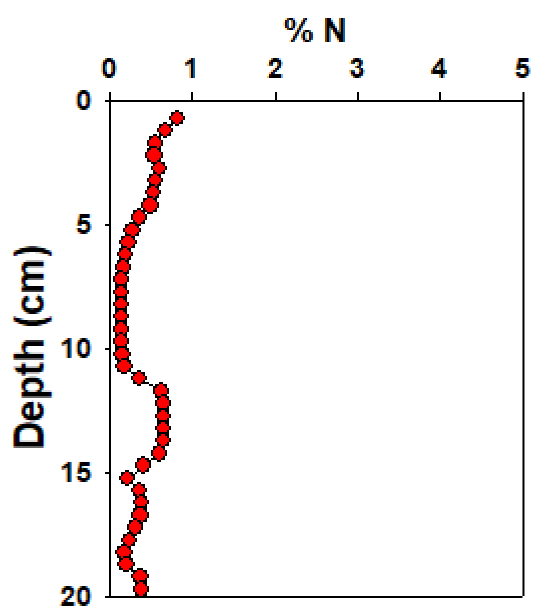

Figure A.4 Total nitrogen content in Isadore's Lake expressed as mass %.

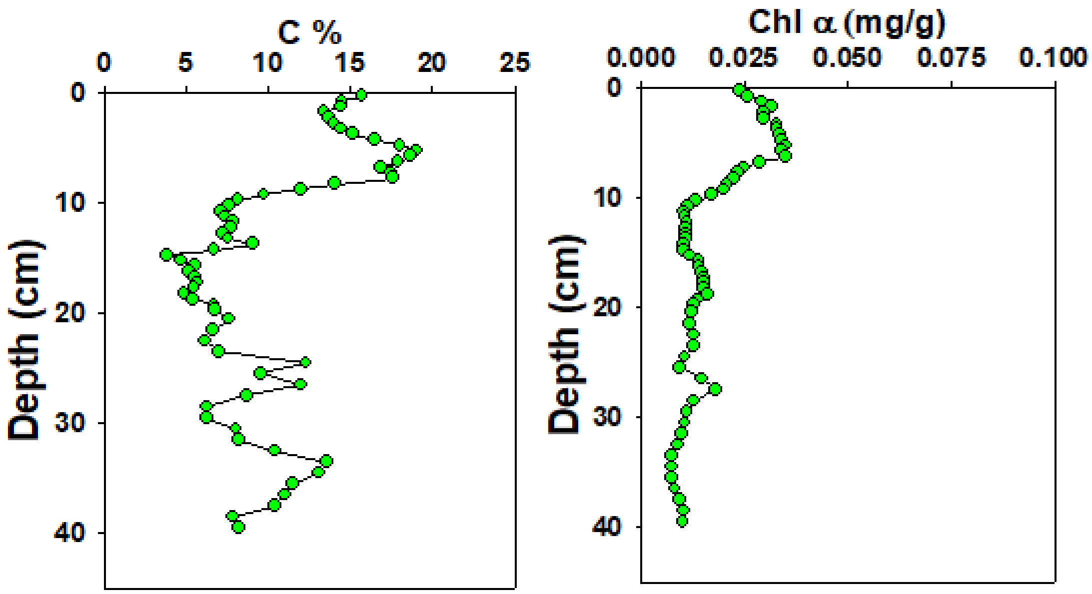

Figure A.5 Total carbon content expressed as weight % of sample mass for Shipyard Lake, and chlorophyll α counts expressed as mg/g for Shipyard Lake.

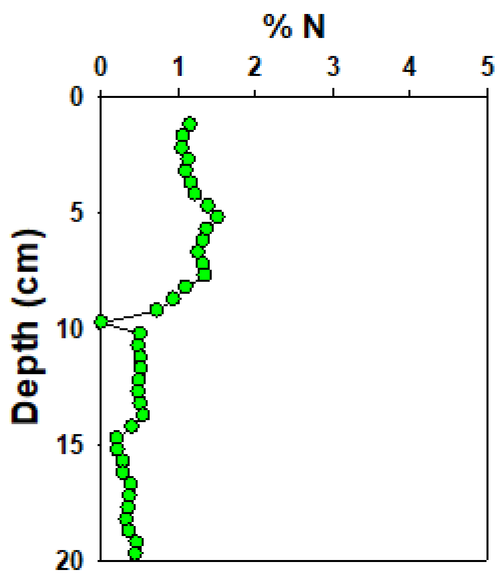

Figure A.6 Total nitrogen content in Shipyard Lake expressed as mass %.

APPENDIX B

Table B.1 Physical properties and nutrient data for cores C-NE20, I1, and S1 from NE20, Isadore’s Lake, and Shipyard Lake, respectively.

Lake	Sampling Date	Midpoint Depth (cm)	Magnetic Susceptibility (10^-8 m3/kg)	%Clay	%Silt	%Sand	C LECO Induction Furnace wt %	Org C [NE20 Only]	Chla family - VR (mg/g dry wt.)
NE20	10-Mar-16	0.25		0.00	78.95	21.05		29.41	
NE20	10-Mar-16	0.75						29.17	
NE20	10-Mar-16	1.25		0.00	74.23	25.77			
NE20	10-Mar-16	1.75						25.08	
NE20	10-Mar-16	2.25		0.14	63.59	36.28			
NE20	10-Mar-16	2.75						29.43	
NE20	10-Mar-16	3.25							
NE20	10-Mar-16	3.75		3.72	76.85	19.44		25.45	
NE20	10-Mar-16	4.25		12.51	74.82	12.67			
NE20	10-Mar-16	4.75		9.02	52.69	38.29		30.31	
NE20	10-Mar-16	5.25		8.87	70.58	20.55			
NE20	10-Mar-16	5.75		12.87	70.29	16.84		28.4	
NE20	10-Mar-16	6.25		1.48	63.90	34.63			
NE20	10-Mar-16	6.75		1.42	58.43	40.15		28.29	
NE20	10-Mar-16	7.25							
NE20	10-Mar-16	7.75						31.44	
NE20	10-Mar-16	8.25		0.00	40.79	59.21			
NE20	10-Mar-16	8.75		0.00	40.81	59.20		30.9	
NE20	10-Mar-16	9.25		0.00	53.26	46.75			
NE20	10-Mar-16	9.75		0.15	74.58	25.27		31.9	
NE20	10-Mar-16	10.25							
NE20	10-Mar-16	10.75		0.00	67.09	32.91		25.84	
NE20	10-Mar-16	11.25							
NE20	10-Mar-16	11.75		0.00	75.12	24.89		23.56	
NE20	10-Mar-16	12.25							

NE20	10-Mar-16	12.75	0.00	70.96	29.04	20.97
NE20	10-Mar-16	13.25	0.13	75.05	24.82	
NE20	10-Mar-16	13.75	1.50	87.50	11.00	19.28
NE20	10-Mar-16	14.25	0.14	83.26	16.60	
NE20	10-Mar-16	14.75	0.39	72.53	27.08	23.76
NE20	10-Mar-16	15.25	3.05	79.82	17.13	
NE20	10-Mar-16	15.75	0.34	87.26	12.40	23.16
NE20	10-Mar-16	16.25				
NE20	10-Mar-16	16.75	4.72	80.71	14.57	26.8
NE20	10-Mar-16	17.25	0.15	75.42	24.43	
NE20	10-Mar-16	17.75	0.11	83.85	16.04	34.79
NE20	10-Mar-16	18.25	0.00	94.73	5.28	
NE20	10-Mar-16	18.75	0.00	43.12	56.89	32.34
NE20	10-Mar-16	19.25	0.00	51.32	48.68	
NE20	10-Mar-16	19.75	0.12	47.29	52.60	19.81
NE20	10-Mar-16	20.5	0.00	55.06	44.94	
NE20	10-Mar-16	21.5	0.00	48.73	51.27	
NE20	10-Mar-16	22.5	4.15	62.59	33.27	
NE20	10-Mar-16	23.5	0.00	46.52	53.48	
NE20	10-Mar-16	24.5	0.32	58.91	40.77	
NE20	10-Mar-16	25.5	4.93	65.78	29.30	
NE20	10-Mar-16	26.5	0.95	59.47	39.58	
NE20	10-Mar-16	27.5	5.27	55.30	39.43	
NE20	10-Mar-16	28.5	7.82	52.85	39.33	
NE20	10-Mar-16	29.5	8.77	58.15	33.08	
NE20	10-Mar-16	30.5	6.34	47.46	46.20	
NE20	10-Mar-16	31.5	0.58	61.63	37.80	
NE20	10-Mar-16	32.5	0.49	43.76	55.76	
NE20	10-Mar-16	33.5	7.87	54.60	37.53	
NE20	10-Mar-16	34.5	0.34	41.26	58.40	
NE20	10-Mar-16	35.5	6.83	58.83	34.35	
NE20	10-Mar-16	36.5	0.13	58.49	41.38	

NE20	10-Mar-16	37.5		0.00	52.18	47.82		
NE20	10-Mar-16	38.5		0.00	49.95	50.05		
NE20	10-Mar-16	39.5		0.59	47.29	52.12		
NE20	10-Mar-16	40.5		6.08	51.49	42.43		
NE20	10-Mar-16	41.5		7.02	56.98	36.01		
NE20	10-Mar-16	42.5		0.11	53.57	46.32		
NE20	10-Mar-16	43.5		6.62	74.23	19.16		
Isadore's	4-Mar-16	0.25	0.576035				8.16	0.059047
Isadore's	4-Mar-16	0.75	1.46526				6.86	0.052683
Isadore's	4-Mar-16	1.25	0.488553				6.11	0.05434
Isadore's	4-Mar-16	1.75	1.098063				5.48	0.041111
Isadore's	4-Mar-16	2.25	1.272953	17.39	11.59	71.01	5.41	0.042214
Isadore's	4-Mar-16	2.75	1.591046	40.70	9.77	49.54	5.88	0.043145
Isadore's	4-Mar-16	3.25	1.616382	17.73	11.82	70.45	5.52	0.032831
Isadore's	4-Mar-16	3.75	2.237163	23.71	5.95	70.34	5.29	0.021401
Isadore's	4-Mar-16	4.25	3.080597	32.68	21.56	45.76	5.03	0.018555
Isadore's	4-Mar-16	4.75	6.202596	26.18	24.18	49.64	4.15	0.011932
Isadore's	4-Mar-16	5.25	11.30326	14.62	8.18	77.20	3.53	0.007606
Isadore's	4-Mar-16	5.75	11.31546	10.32	5.03	84.65	3.06	0.007487
Isadore's	4-Mar-16	6.25	9.572961	11.00	7.05	81.96	2.71	0.004661
Isadore's	4-Mar-16	6.75	7.185162	14.66	17.28	68.06	2.67	0.003523
Isadore's	4-Mar-16	7.25	4.47716	11.27	10.03	78.69	2.58	0.003748
Isadore's	4-Mar-16	7.75	3.216924	10.01	9.23	80.76	2.52	0.003107
Isadore's	4-Mar-16	8.25	2.369415	9.45	7.68	82.87	2.48	0.00362
Isadore's	4-Mar-16	8.75	2.929729	8.59	7.75	83.66	2.46	0.00287
Isadore's	4-Mar-16	9.25	2.394317	10.07	9.14	80.79	2.52	0.003526
Isadore's	4-Mar-16	9.75	2.585911	9.21	7.27	83.52	2.65	0.004868
Isadore's	4-Mar-16	10.25	2.025098	24.82	46.83	28.35	2.96	0.01245
Isadore's	4-Mar-16	10.75	1.431597	23.92	23.46	52.62	3.41	0.023009
Isadore's	4-Mar-16	11.25	1.177603	21.00	14.00	65.00	5.73	0.0312
Isadore's	4-Mar-16	11.75	1.126089	23.36	9.34	67.30	10.6	0.0301
Isadore's	4-Mar-16	12.25	1.89901	24.56	12.40	63.04	11.4	0.019667

Isadore's	4-Mar-16	12.75	2.610685	33.38	25.48	41.14	11.1	0.014497
Isadore's	4-Mar-16	13.25	5.619108	30.57	31.37	38.06	10.3	0.0116
Isadore's	4-Mar-16	13.75	6.258313	37.37	19.69	42.94	9.72	0.014117
Isadore's	4-Mar-16	14.25	5.841833	20.77	9.86	69.37	8.79	0.008741
Isadore's	4-Mar-16	14.75	9.025966	17.00	11.39	71.61	5.93	0.005145
Isadore's	4-Mar-16	15.25	6.825599	27.67	22.92	49.41	3.64	0.011811
Isadore's	4-Mar-16	15.75	4.427837	16.42	2.18	81.40	4.87	0.012064
Isadore's	4-Mar-16	16.25	3.428052	24.08	16.72	59.20	5.56	0.011478
Isadore's	4-Mar-16	16.75	3.108259	16.87	6.25	76.88	5.35	0.008798
Isadore's	4-Mar-16	17.25	2.978633	27.12	31.01	41.86	5.01	0.004323
Isadore's	4-Mar-16	17.75	3.789395	15.02	10.68	74.30	4.13	0.004216
Isadore's	4-Mar-16	18.25	2.938661	9.85	24.48	65.67	3.49	0.007136
Isadore's	4-Mar-16	18.75	2.064303	32.90	14.49	52.61	3.87	0.009436
Isadore's	4-Mar-16	19.25	3.797637	23.83	17.85	58.32	5.76	0.010645
Isadore's	4-Mar-16	19.75	4.069073	15.16	3.41	81.43	5.97	0.013813
Isadore's	4-Mar-16	20.5	3.834233	27.76	29.06	43.18	5.25	0.012582
Isadore's	4-Mar-16	21.5	2.862347	26.50	37.13	36.37	3.58	0.003995
Isadore's	4-Mar-16	22.5	6.966028	23.93	36.80	39.27	4.15	0.006746
Isadore's	4-Mar-16	23.5	12.88643	20.46	34.03	45.51	4.78	0.013085
Isadore's	4-Mar-16	24.5	4.923427			35.06	3.91	0.005858
Isadore's	4-Mar-16	25.5	3.386089	31.89	31.76	36.34	3.19	0.005973
Isadore's	4-Mar-16	26.5	2.467958	25.74	37.85	36.41	3.26	0.00325
Isadore's	4-Mar-16	27.5	3.408061	26.21	32.00	41.79	4.49	0.004109
Isadore's	4-Mar-16	28.5	7.729459	23.88	29.90	46.22	4.58	0.012082
Isadore's	4-Mar-16	29.5	8.965236			41.23	5.61	0.012897
Isadore's	4-Mar-16	30.5	15.5944	18.80	42.39	38.81	8.31	0.014264
Isadore's	4-Mar-16	31.5	6.328697	17.81	50.52	31.67	4.84	0.007107
Isadore's	4-Mar-16	32.5	6.433194	17.05	54.82	28.13	4.63	0.010669
Isadore's	4-Mar-16	33.5	8.585224	24.91	29.00	46.09	8.61	0.012124
Isadore's	4-Mar-16	34.5	7.704323	25.31	24.29	50.40	5.16	0.010269
Isadore's	4-Mar-16	35.5	6.112422	25.75	31.93	42.32	4.18	0.011158
Isadore's	4-Mar-16	36.5	4.492777	25.50	25.22	49.28	4.69	0.00931

Isadore's	4-Mar-16	37.5	6.466794	27.56	24.94	47.51	4.59	0.009947
Isadore's	4-Mar-16	38.5	3.232494	27.67	29.32	43.02	4.26	0.002663
Isadore's	4-Mar-16	39.5	2.830528	23.72	51.77	24.51	2.4	0.001919
Shipyard	5-Mar-16	0.25	1.567859	36.59	4.88	58.54	15.7	0.024049
Shipyard	5-Mar-16	0.75	2.486748	50.59	6.75	42.67	14.5	0.025758
Shipyard	5-Mar-16	1.25	3.267926	53.79	7.17	39.04	14.4	0.029378
Shipyard	5-Mar-16	1.75	4.100241	51.90	6.92	41.18	13.4	0.031786
Shipyard	5-Mar-16	2.25	5.179969	39.67	5.29	55.04	13.7	0.029832
Shipyard	5-Mar-16	2.75	6.23189	42.67	5.69	51.64	14	0.029556
Shipyard	5-Mar-16	3.25	7.868875	46.60	6.21	47.19	14.4	0.03278
Shipyard	5-Mar-16	3.75	7.406546	60.73	8.10	31.17	15.2	0.032919
Shipyard	5-Mar-16	4.25	8.578454	47.60	6.35	46.05	16.5	0.033481
Shipyard	5-Mar-16	4.75	7.689635	40.21	5.36	54.43	18	0.033969
Shipyard	5-Mar-16	5.25	9.493789	46.22	6.16	47.62	19	0.034903
Shipyard	5-Mar-16	5.75	9.524277	49.22	6.56	44.22	18.7	0.034047
Shipyard	5-Mar-16	6.25	8.078335	53.92	7.19	38.89	17.9	0.034916
Shipyard	5-Mar-16	6.75	5.562854	51.59	6.86	41.56	16.9	0.02859
Shipyard	5-Mar-16	7.25	5.396965	41.49	5.53	52.98	17.5	0.024951
Shipyard	5-Mar-16	7.75	5.515025	40.60	2.44	56.96	17.6	0.023209
Shipyard	5-Mar-16	8.25	5.224327	37.24	3.86	58.90	14.1	0.022357
Shipyard	5-Mar-16	8.75	5.192632	44.90	6.63	48.47	12	0.020689
Shipyard	5-Mar-16	9.25	4.823151	24.25	12.78	62.97	9.76	0.020027
Shipyard	5-Mar-16	9.75	4.564916	51.73	7.06	41.21	8.19	0.01714
Shipyard	5-Mar-16	10.25	4.509255	30.96	24.73	44.30	7.63	0.013355
Shipyard	5-Mar-16	10.75	3.443255	19.78	35.86	44.36	7.16	0.011336
Shipyard	5-Mar-16	11.25	2.929414	7.87	48.98	43.15	7.43	0.010266
Shipyard	5-Mar-16	11.75	2.489042	19.66	27.90	52.44	7.85	0.010631
Shipyard	5-Mar-16	12.25	2.449454	28.67	18.05	53.27	7.72	0.011034
Shipyard	5-Mar-16	12.75	2.200464	36.79	20.31	42.90	7.25	0.010712
Shipyard	5-Mar-16	13.25	2.404994	43.81	14.83	41.36	7.59	0.010817
Shipyard	5-Mar-16	13.75	2.453962	35.34	21.25	43.40	9.12	0.010894
Shipyard	5-Mar-16	14.25	2.260549	31.19	21.62	47.19	6.72	0.010417

Shipyard	5-Mar-16	14.75	2.328611	31.42	21.88	46.70	3.9	0.010481
Shipyard	5-Mar-16	15.25	2.502216	29.17	20.45	50.38	4.68	0.011698
Shipyard	5-Mar-16	15.75	2.525829	7.76	5.18	87.06	5.54	0.013931
Shipyard	5-Mar-16	16.25	2.411775	8.37	5.58	86.05	5.18	0.014008
Shipyard	5-Mar-16	16.75	2.744284	0.86	0.57	98.57	5.58	0.01483
Shipyard	5-Mar-16	17.25	2.616171	6.60	2.20	91.20	5.7	0.015054
Shipyard	5-Mar-16	17.75	2.658982	18.16	5.43	76.41	5.52	0.015147
Shipyard	5-Mar-16	18.25	2.836518	18.51	4.26	77.23	4.91	0.015057
Shipyard	5-Mar-16	18.75	2.916991	23.03	16.91	60.06	5.44	0.016143
Shipyard	5-Mar-16	19.25	2.482697	7.67	1.63	90.70	6.73	0.013693
Shipyard	5-Mar-16	19.75	2.237352	9.84	1.43	88.74	6.75	0.012843
Shipyard	5-Mar-16	20.5	1.807414	34.78	25.24	39.98	7.67	0.012098
Shipyard	5-Mar-16	21.5	1.741957	29.95	21.47	48.58	6.68	0.011821
Shipyard	5-Mar-16	22.5	2.216678	30.77	21.24	47.99	6.2	0.012734
Shipyard	5-Mar-16	23.5	2.232514	33.34	22.23	44.43	7	0.012636
Shipyard	5-Mar-16	24.5	2.028714	35.62	26.20	38.19	12.3	0.010549
Shipyard	5-Mar-16	25.5	1.968058	31.84	21.77	46.40	9.57	0.009248
Shipyard	5-Mar-16	26.5	2.098419	35.20	21.08	43.71	12	0.014844
Shipyard	5-Mar-16	27.5	2.540791	33.36	23.59	43.05	8.71	0.018035
Shipyard	5-Mar-16	28.5	2.336357	32.39	22.37	45.24	6.28	0.012843
Shipyard	5-Mar-16	29.5	2.743217	29.28	15.61	55.11	6.29	0.011131
Shipyard	5-Mar-16	30.5	2.099057	32.09	17.18	50.73	8.06	0.010643
Shipyard	5-Mar-16	31.5	1.784607	31.18	16.25	52.57	8.29	0.00988
Shipyard	5-Mar-16	32.5	1.923158	33.26	22.98	43.76	10.4	0.008892
Shipyard	5-Mar-16	33.5	1.753118	32.14	19.96	47.90	13.6	0.007539
Shipyard	5-Mar-16	34.5	1.643157	30.96	17.09	51.95	13.1	0.007428
Shipyard	5-Mar-16	35.5	1.458721	13.82	36.23	49.95	11.5	0.007609
Shipyard	5-Mar-16	36.5	1.453765	8.16	33.19	58.65	11	0.008175
Shipyard	5-Mar-16	37.5	1.52906	20.52	20.69	58.79	10.4	0.009518
Shipyard	5-Mar-16	38.5	2.137065	17.11	32.60	50.29	7.92	0.010482
Shipyard	5-Mar-16	39.5	2.19123	15.46	22.57	61.98	8.2	0.010111

Table B.2 Activities of 210-Pb and 137 Cs with estimated dates and sedimentation rates based on CRS age models for cores C-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	210- Pb Uns. Activity [Bq/kg]	137-Cs Activity (Bq/kg)	Estimated Date (CRS Model)	Sed. Rate [g/cm^2/y] (CRS Model)
NE20	0.25	0.37	0.04	2010	0.010761
NE20	0.75			2005.62	
NE20	1.25	0.35	0.05	2001.24	0.009039
NE20	1.75			1996.38	
NE20	2.25	0.30	0.05	1992	0.007904
NE20	2.75			1986.767	
NE20	3.25	0.24	0.07	1982	0.007327
NE20	3.75			1976.408	
NE20	4.25	0.21	0.09	1970.802	0.006236
NE20	4.75			1966.09	
NE20	5.25	0.13	0.09	1961	0.00744
NE20	5.75			1957.249	
NE20	6.25	0.09	0.04	1953.119	0.008135
NE20	6.75			1948.745	
NE20	7.25	0.07	0.02	1944	0.008288
NE20	7.75			1939.488	
NE20	8.25	0.06	0.02	1934.605	0.007463
NE20	8.75			1929.162	
NE20	9.25	0.05	0.02	1924	0.007252
NE20	9.75			1917.874	
NE20	10.25	0.04	0.01	1912.03	0.006844
NE20	10.75			1904.103	
NE20	11.25	0.01	0.01	1896	
NE20	11.75			1890.923	
NE20	12.25	0.01	0.01	1886	
NE20	12.75			1879.445	
NE20	13.25	0.00	0.00	1873	
NE20	13.75			1866.887	

NE20	14.25	0.01	0.00	1861
NE20	14.75			1854.277
NE20	15.25	0.00	0.00	1848
NE20	15.75			1842.461
NE20	16.25	0.00	0.00	1837
NE20	16.75			1831.453
NE20	17.25	0.00	0.01	1826
NE20	17.75			1821
NE20	18.25			1816
NE20	18.75			1811
NE20	19.25			1806
NE20	19.75			1801
NE20	20.5			1796
NE20	21.5			1791
NE20	22.5			1786
NE20	23.5			1781
NE20	24.5			1776
NE20	25.5			1771
NE20	26.5			1766
NE20	27.5			1761
NE20	28.5			1756
NE20	29.5			1751
NE20	30.5			1746
NE20	31.5			1741
NE20	32.5			1736
NE20	33.5			1731
NE20	34.5			1726
NE20	35.5			1721
NE20	36.5			1716
NE20	37.5			1711
NE20	38.5			1706
NE20	39.5			1701

NE20	40.5			1696	
NE20	41.5			1691	
NE20	42.5			1686	
NE20	43.5			1681	
Isadore's	0.25	64.97	2.06	2015.99	0.1555
Isadore's	0.75	104.48	1.60	2015.49	0.0952
Isadore's	1.25	111.59	1.35	2014.72	0.087
Isadore's	1.75	79.52	1.44	2013.88	0.1189
Isadore's	2.25	94.54	1.39	2012.98	0.0973
Isadore's	2.75	80.97	1.21	2011.95	0.11
Isadore's	3.25	71.08	1.23	2010.89	0.1212
Isadore's	3.75			2009.85	
Isadore's	4.25			2008.805	
Isadore's	4.75	30.98	1.08	2007.68	0.2517
Isadore's	5.25			2006.968	
Isadore's	5.75			2006.256	
Isadore's	6.25			2005.544	
Isadore's	6.75			2004.832	
Isadore's	7.25	7.02	0.94	2004.12	0.9939
Isadore's	7.75			2002.636	
Isadore's	8.25			2001.152	
Isadore's	8.75			1999.668	
Isadore's	9.25			1998.184	
Isadore's	9.75	46.88	1.08	1996.7	0.1181
Isadore's	10.25			1990.309	
Isadore's	10.75			1988.23	
Isadore's	11.25	102.30	1.90	1986.39	0.0393
Isadore's	11.75	119.46	2.15	1983.74	0.031
Isadore's	12.25	22.10	2.10	1981.94	0.1583
Isadore's	12.75	117.37	2.15	1980.06	0.0281
Isadore's	13.25			1977.19	
Isadore's	13.75	36.13	1.99	1974.32	0.0763

Isadore's	14.25			1972.535	
Isadore's	14.75	11.37	1.43	1970.75	0.2172
Isadore's	15.25			1969.118	
Isadore's	15.75			1967.485	
Isadore's	16.25			1965.853	
Isadore's	16.75	16.89	2.28	1964.22	0.1193
Isadore's	17.25			1963.203	
Isadore's	17.75			1962.185	
Isadore's	18.25			1961.168	
Isadore's	18.75	0.00	2.32	1960.15	
Isadore's	19.25			1960.145	
Isadore's	19.75			1960.14	
Isadore's	20.5			1960.135	
Isadore's	21.5	0.06	1.19	1960.13	28.0216
Isadore's	22.5			1959.26	
Isadore's	23.5			1958.39	
Isadore's	24.5			1957.52	
Isadore's	25.5	4.43	0.93	1956.65	0.3594
Isadore's	26.5			1954.52	
Isadore's	27.5			1952.39	
Isadore's	28.5			1950.26	
Isadore's	29.5	7.06	1.09	1948.13	0.1729
Isadore's	30.5			1946	
Isadore's	31.5			1943.87	
Isadore's	32.5			1941.74	
Isadore's	33.5			1939.61	
Isadore's	34.5			1937.48	
Isadore's	35.5			1935.35	
Isadore's	36.5			1933.22	
Isadore's	37.5			1931.09	
Isadore's	38.5			1928.96	
Isadore's	39.5			1926.83	

Shipyard	0.25	64.20	1.31	2015.58	0.0795
Shipyard	0.75	90.15	2.12	2014.19	0.0542
Shipyard	1.25	108.06	2.09	2012.49	0.0429
Shipyard	1.75	117.74	2.65	2010.58	0.0371
Shipyard	2.25	131.61	2.87	2008.46	0.0311
Shipyard	2.75	141.43	3.25	2006.23	0.027
Shipyard	3.25	151.98	5.87	2003.92	0.0234
Shipyard	3.75	141.61	1.78	2001.61	0.0233
Shipyard	4.25	211.93	1.03	1998.79	0.0143
Shipyard	4.75	183.73	0.00	1995.47	0.0148
Shipyard	5.25	155.94	3.05	1992.39	0.0159
Shipyard	5.75	157.31	2.48	1989.15	0.0142
Shipyard	6.25			1984.367	
Shipyard	6.75			1979.583	
Shipyard	7.25	77.27	16.56	1974.8	0.0185
Shipyard	7.75			1969.895	
Shipyard	8.25	40.02	20.87	1964.99	0.0264
Shipyard	8.75	28.32	26.24	1960.96	0.0329
Shipyard	9.25	53.48	26.07	1955.02	0.0145
Shipyard	9.75	30.35	30.28	1946.8	0.0197
Shipyard	10.25	14.96	26.44	1940.17	0.0326
Shipyard	10.75	19.69	23.61	1932.59	0.0196
Shipyard	11.25	6.06	19.75	1921.61	0.0452
Shipyard	11.75	0.00	15.13	1918.39	
Shipyard	12.25	3.74	13.56	1916.85	0.063
Shipyard	12.75			1883.82	
Shipyard	13.25	30.05	7.35	1850.79	0.001
Shipyard	13.75			1843.79	
Shipyard	14.25			1836.79	
Shipyard	14.75	0.00	4.40	1829.79	
Shipyard	15.25			1822.79	
Shipyard	15.75			1815.79	

Shipyard	16.25	1808.79
Shipyard	16.75	1801.79
Shipyard	17.25	1794.79
Shipyard	17.75	1787.79
Shipyard	18.25	1780.79
Shipyard	18.75	1773.79
Shipyard	19.25	1766.79
Shipyard	19.75	1759.79
Shipyard	20.5	1752.79
Shipyard	21.5	1745.79
Shipyard	22.5	1738.79
Shipyard	23.5	1731.79
Shipyard	24.5	1724.79
Shipyard	25.5	1717.79
Shipyard	26.5	1710.79
Shipyard	27.5	1703.79
Shipyard	28.5	1696.79
Shipyard	29.5	1689.79
Shipyard	30.5	1682.79
Shipyard	31.5	1675.79
Shipyard	32.5	1668.79
Shipyard	33.5	1661.79
Shipyard	34.5	1654.79
Shipyard	35.5	1647.79
Shipyard	36.5	1640.79
Shipyard	37.5	1633.79
Shipyard	38.5	1626.79
Shipyard	39.5	1619.79

Table B.3 Partial digestion metal concentrations Ag-Eu for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Ag ICP MS Partial mg/kg	As ICP MS Partial mg/kg	Be ICP MS Partial mg/kg	Bi ICP MS Partial mg/kg	Cd ICP MS Partial mg/kg	Co ICP MS Partial mg/kg	Cs ICP MS Partial mg/kg	Cu ICP MS Partial mg/kg	Dy ICP MS Partial mg/kg	Er ICP MS Partial mg/kg	Eu ICP MS Partial mg/kg
NE20	0.25	0.09	1.44	0.13	0.84	0.34	2.51	0.14	6.11	0.57	0.24	0.13
NE20	0.75	0.04	1.44	0.06	0.21	0.22	2.4	0.14	4.02	0.22	0.11	0.09
NE20	1.25	0.03	1.47	0.05	0.13	0.22	2.15	0.13	3.65	0.18	0.09	0.08
NE20	1.75	0.03	1.74	0.03	0.12	0.25	1.94	0.14	3.95	0.16	0.08	0.07
NE20	2.25	0.04	1.73	0.05	0.11	0.27	1.82	0.14	4.17	0.15	0.07	0.07
NE20	2.75	0.03	1.22	0.03	0.09	0.24	1.64	0.11	3.64	0.13	0.07	0.06
NE20	3.25	0.03	1.36	0.03	0.08	0.25	1.84	0.11	4.06	0.13	0.07	0.07
NE20	3.75	0.03	1.14	0.05	0.06	0.21	1.72	0.11	3.82	0.13	0.07	0.07
NE20	4.25	0.02	1	0.02	0.03	0.16	1.6	0.12	3.22	0.11	0.06	0.07
NE20	4.75	0.02	0.67	0.02	0.03	0.14	1.37	0.09	2.49	0.1	0.06	0.06
NE20	5.25	0.01	0.54	0.02	0.02	0.11	1.09	0.07	1.72	0.07	0.04	0.05
NE20	5.75	0.02	0.87	0.02	0.02	0.15	1.38	0.11	2.23	0.11	0.05	0.07
NE20	6.25	0.02	0.71	0.02	0.02	0.17	1.35	0.12	2.57	0.12	0.06	0.07
NE20	6.75	0.02	0.67	0.03	0.03	0.21	1.28	0.12	2.97	0.12	0.06	0.06
NE20	7.25	0.03	0.77	0.03	0.04	0.24	1.35	0.13	3.37	0.13	0.07	0.06
NE20	7.75	0.02	0.67	0.04	0.03	0.24	1.28	0.12	3.42	0.13	0.08	0.05
NE20	8.25	0.04	0.68	0.05	0.03	0.29	1.4	0.14	4.33	0.15	0.08	0.07
NE20	8.75	0.04	0.69	0.04	0.03	0.27	1.5	0.14	4.58	0.15	0.08	0.06
NE20	9.25	0.04	0.69	0.03	0.03	0.27	1.36	0.13	4.5	0.13	0.06	0.05
NE20	9.75	0.03	0.58	0.02	0.19	0.25	1.2	0.11	3.76	0.13	0.07	0.04
NE20	10.25	0.04	0.7	0.04	0.07	0.33	1.53	0.15	4.3	0.16	0.08	0.06
NE20	10.75	0.02	0.75	0.05	0.05	0.25	1.14	0.11	3.72	0.12	0.06	0.04
NE20	11.25	0.02	0.74	0.03	0.05	0.29	1.07	0.09	3.99	0.13	0.06	0.05
NE20	11.75	0.02	0.46	0.03	0.03	0.2	0.93	0.08	2.71	0.1	0.04	0.04
NE20	12.25	0.03	0.7	0.04	0.04	0.32	1.48	0.13	4.16	0.16	0.08	0.06
NE20	12.75	0.02	0.5	0.03	0.03	0.26	1.27	0.1	3.13	0.12	0.06	0.04

NE20	13.25	0.03	0.65	0.04	0.04	0.3	1.47	0.13	4.01	0.15	0.08	0.06
NE20	13.75	0.02	0.48	0.03	0.02	0.23	1.06	0.09	2.53	0.11	0.06	0.04
NE20	14.25	0.03	0.89	0.02	0.03	0.34	1.55	0.14	3.71	0.17	0.09	0.06
NE20	14.75	0.02	0.41	0.01	0.02	0.21	0.95	0.09	2.17	0.1	0.05	0.04
NE20	15.25	0.02	0.52	0.02	0.02	0.26	1.17	0.11	2.68	0.13	0.06	0.05
NE20	15.75	0.03	0.56	0.03	0.03	0.29	1.32	0.12	3.18	0.14	0.07	0.05
NE20	16.25	0.04	0.47	0.03	0.04	0.34	1.17	0.14	2.9	0.18	0.08	0.07
NE20	16.75	0.03	0.72	0.02	0.02	0.34	1.33	0.13	4.03	0.14	0.07	0.05
NE20	17.25	0.03	0.78	0.03	0.03	0.31	1.48	0.12	3.54	0.15	0.08	0.06
NE20	17.75	0.02	0.5	0.03	0.02	0.23	1.04	0.09	2.87	0.11	0.06	0.04
NE20	18.25	0.04	0.78	0.04	0.02	0.3	1.3	0.12	3.71	0.15	0.08	0.05
NE20	18.75	0.04	0.42	0.01	0.2	0.2	0.94	0.07	2.82	0.1	0.06	0.04
NE20	19.25	0.03	0.47	0.03	0.08	0.21	0.96	0.07	3.06	0.12	0.06	0.04
NE20	19.75	0.03	0.52	0.02	0.06	0.23	1.07	0.08	3.05	0.12	0.07	0.05
NE20	20.5	0.04	0.74	0.05	0.06	0.3	1.52	0.13	4.16	0.17	0.08	0.07
NE20	21.5	0.03	0.59	0.04	0.04	0.25	1.21	0.1	3.12	0.14	0.08	0.05
NE20	22.5	0.04	0.63	0.04	0.04	0.28	1.33	0.1	3.39	0.15	0.08	0.06
NE20	23.5	0.04	0.78	0.02	0.04	0.3	1.72	0.12	3.83	0.16	0.08	0.07
NE20	24.5	0.04	0.69	0.04	0.03	0.28	1.57	0.1	3.8	0.17	0.08	0.07
NE20	25.5	0.02	0.4	0.02	0.02	0.22	0.98	0.07	2.88	0.12	0.06	0.05
NE20	26.5	0.04	0.6	0.04	0.03	0.32	1.44	0.12	3.49	0.17	0.09	0.07
NE20	27.5	0.03	0.57	0.03	0.03	0.3	1.28	0.11	3.28	0.14	0.08	0.07
NE20	28.5	0.03	0.82	0.02	0.03	0.25	1.21	0.1	2.93	0.15	0.08	0.07
NE20	29.5	0.03	0.58	0.04	0.02	0.23	0.98	0.09	2.93	0.13	0.06	0.06
NE20	30.5	0.02	0.68	0.03	0.02	0.21	0.91	0.08	3.37	0.12	0.06	0.06
NE20	31.5	0.02	0.51	0.01	0.02	0.18	0.66	0.06	2.57	0.1	0.05	0.05
NE20	32.5	0.02	0.66	0.02	0.02	0.21	0.87	0.09	3.11	0.13	0.06	0.06
NE20	33.5	0.02	0.42	0.02	0.01	0.17	0.65	0.07	2.42	0.09	0.05	0.05
NE20	34.5	0.02	0.62	0.01	0.02	0.21	0.87	0.1	2.6	0.12	0.06	0.07
NE20	35.5	0.03	0.49	0.02	0.02	0.22	1.02	0.12	3	0.13	0.06	0.07
NE20	36.5	0.04	0.92	0.02	0.32	0.22	1.19	0.14	4.97	0.16	0.08	0.06
NE20	37.5	0.02	0.47	0.01	0.07	0.16	0.71	0.08	2.64	0.09	0.05	0.04

NE20	38.5	0.02	1.18	0.02	0.06	0.19	1	0.1	3.04	0.12	0.06	0.06
NE20	39.5	0.02	0.69	0.02	0.04	0.23	1.07	0.1	2.31	0.11	0.06	0.07
NE20	40.5	0.02	0.65	0.03	0.02	0.19	0.95	0.07	2.43	0.09	0.05	0.07
NE20	41.5	0.02	0.72	<0.01	0.02	0.15	0.95	0.07	2.48	0.09	0.04	0.07
NE20	42.5	0.02	0.65	0.02	0.01	0.12	0.75	0.05	1.61	0.07	0.04	0.08
NE20	43.5	0.01	0.71	0.02	0.01	0.08	0.61	0.04	1.31	0.06	0.03	0.08
Isadore's	0.25	0.08	3.5	0.58	0.26	0.24	8.02	1.43	20.5	2.08	1	0.62
Isadore's	0.75	0.06	2.99	0.62	0.19	0.27	8.23	1.09	20.4	2.19	1.06	0.65
Isadore's	1.25	0.06	3.38	0.62	0.2	0.28	8.8	0.74	20.7	2.24	1.11	0.66
Isadore's	1.75	0.06	3.36	0.61	0.2	0.27	8.53	0.72	19.9	2.29	1.1	0.65
Isadore's	2.25	0.06	3.6	0.62	0.2	0.27	9.02	0.78	21.2	2.42	1.17	0.7
Isadore's	2.75	0.06	3.72	0.61	0.21	0.27	8.58	0.74	20.4	2.33	1.13	0.66
Isadore's	3.25	0.06	3.91	0.63	0.21	0.26	8.77	0.76	20.6	2.39	1.15	0.7
Isadore's	3.75	0.06	4.2	0.55	0.2	0.28	8.68	0.77	20.4	2.37	1.16	0.7
Isadore's	4.25	0.06	4.48	0.54	0.21	0.28	8.74	0.76	20.1	2.36	1.16	0.7
Isadore's	4.75	0.06	5.26	0.65	0.21	0.28	9.36	0.82	20.8	2.54	1.24	0.72
Isadore's	5.25	0.06	5.42	0.64	0.21	0.3	9.25	0.85	20.6	2.55	1.23	0.74
Isadore's	5.75	0.07	5.28	0.58	0.22	0.3	9.67	0.9	21.3	2.67	1.28	0.77
Isadore's	6.25	0.07	4.5	0.62	0.21	0.29	9.66	0.96	21	2.66	1.28	0.78
Isadore's	6.75	0.06	4.21	0.65	0.22	0.31	9.93	0.93	21.4	2.74	1.34	0.82
Isadore's	7.25	0.06	3.8	0.62	0.2	0.31	9.77	0.96	21.2	2.69	1.31	0.79
Isadore's	7.75	0.06	3.68	0.61	0.2	0.29	9.43	0.86	20.3	2.56	1.25	0.76
Isadore's	8.25	0.06	3.85	0.63	0.21	0.29	9.86	0.93	21.4	2.7	1.31	0.78
Isadore's	8.75	0.07	3.9	0.64	0.21	0.32	9.92	0.9	21.5	2.7	1.34	0.79
Isadore's	9.25	0.07	3.87	0.66	0.21	0.29	9.8	0.95	21.4	2.69	1.28	0.79
Isadore's	9.75	0.06	3.91	0.65	0.21	0.31	9.95	0.97	21.4	2.67	1.3	0.79
Isadore's	10.25	0.07	3.96	0.68	0.21	0.34	9.94	0.94	21.1	2.71	1.31	0.79
Isadore's	10.75	0.07	4.05	0.62	0.2	0.32	9.47	0.89	20.3	2.55	1.25	0.75
Isadore's	11.25	0.06	6.23	0.57	0.18	0.26	8.84	0.71	17.2	2.25	1.09	0.65
Isadore's	11.75	0.03	7.57	0.31	0.11	0.16	5.67	0.34	10	1.21	0.62	0.38
Isadore's	12.25	0.02	7.62	0.22	0.08	0.11	4.17	0.46	7.62	0.9	0.45	0.3
Isadore's	12.75	0.02	11	0.24	0.1	0.13	4.05	0.26	8.37	0.96	0.47	0.3

Isadore's	13.25	0.03	18.1	0.39	0.13	0.17	5.55	0.39	11.4	1.34	0.67	0.42
Isadore's	13.75	0.04	19.5	0.38	0.15	0.22	6.22	0.36	12.5	1.52	0.75	0.46
Isadore's	14.25	0.04	14	0.46	0.17	0.25	7.19	0.4	14.2	1.84	0.91	0.56
Isadore's	14.75	0.06	6.51	0.5	0.22	0.3	7.99	0.72	19	2.52	1.25	0.74
Isadore's	15.25	0.06	4.56	0.6	0.23	0.32	10.3	0.9	21.4	2.64	1.28	0.79
Isadore's	15.75	0.06	4.37	0.65	0.24	0.33	8.53	0.79	19.7	2.73	1.33	0.79
Isadore's	16.25	0.06	4.72	0.67	0.23	0.35	8.6	0.75	19.3	2.66	1.29	0.78
Isadore's	16.75	0.06	4.93	0.65	0.23	0.34	8.94	0.75	19.5	2.64	1.28	0.76
Isadore's	17.25	0.07	4.98	0.61	0.24	0.37	9.43	0.79	20.6	2.73	1.34	0.8
Isadore's	17.75	0.07	4.46	0.68	0.24	0.38	9.84	0.89	21.2	2.75	1.36	0.81
Isadore's	18.25	0.07	4.14	0.63	0.22	0.38	9.8	0.87	19.9	2.8	1.34	0.82
Isadore's	18.75	0.06	4.54	0.66	0.22	0.34	9.66	1.02	19.4	2.72	1.32	0.78
Isadore's	19.25	0.06	7.2	0.69	0.22	0.37	9.91	0.85	19.7	2.7	1.34	0.79
Isadore's	19.75	0.06	6.99	0.65	0.23	0.33	9.74	0.84	19.9	2.59	1.29	0.76
Isadore's	20.5	0.15	6.41	0.82	0.25	0.34	10.8	0.7	25	2.46	1.22	0.74
Isadore's	21.5	0.18	6	0.85	0.26	0.38	12.2	0.91	28	2.73	1.32	0.82
Isadore's	22.5	0.17	7.08	0.8	0.23	0.36	11.3	0.79	25.1	2.66	1.3	0.77
Isadore's	23.5	0.16	9.23	0.73	0.24	0.36	11.5	0.82	24	2.64	1.31	0.77
Isadore's	24.5	0.16	7.34	0.83	0.24	0.37	11.8	0.85	24.8	2.69	1.35	0.81
Isadore's	25.5	0.16	5.73	0.82	0.25	0.4	12.4	0.95	25.6	2.78	1.4	0.83
Isadore's	26.5	0.17	5.61	0.86	0.26	0.39	12.6	0.96	26.2	2.9	1.44	0.86
Isadore's	27.5	0.15	7.55	0.78	0.24	0.36	11.2	0.78	23.7	2.72	1.36	0.78
Isadore's	28.5	0.18	7.81	0.8	0.25	0.32	10.5	0.81	23.7	2.69	1.31	0.79
Isadore's	29.5	0.15	8.55	0.71	0.24	0.32	10.2	0.72	21.8	2.53	1.25	0.76
Isadore's	30.5	0.12	12.6	0.7	0.21	0.3	8.94	0.5	18.3	2.19	1.1	0.65
Isadore's	31.5	0.16	8.51	0.66	0.21	0.34	9.96	0.69	20.8	2.48	1.22	0.74
Isadore's	32.5	0.14	7.21	0.62	0.19	0.3	9.37	0.75	19.3	2.44	1.18	0.72
Isadore's	33.5	0.09	13.5	0.4	0.14	0.19	7.29	0.58	13.6	1.64	0.84	0.51
Isadore's	34.5	0.15	10.2	0.75	0.23	0.31	9.63	0.71	23.1	2.48	1.22	0.74
Isadore's	35.5	0.15	8.49	0.85	0.26	0.3	10.5	0.82	24.2	2.76	1.34	0.82
Isadore's	36.5	0.14	10.1	0.79	0.24	0.31	9.75	0.8	23.4	2.67	1.32	0.78
Isadore's	37.5	0.14	8.76	0.83	0.25	0.35	10.5	0.84	24.2	2.65	1.33	0.79

Isadore's	38.5	0.15	10	0.82	0.28	0.35	10.7	0.85	24.4	2.94	1.5	0.85
Isadore's	39.5	0.17	7.82	0.91	0.31	0.37	11.3	1.02	27.9	3.17	1.56	0.92
Shipyard	0.25	0.06	4.45	0.47	0.17	0.2	6.74	1.08	14.8	1.72	0.82	0.53
Shipyard	0.75	0.04	4.13	0.49	0.16	0.2	6.58	0.76	13.9	1.7	0.86	0.51
Shipyard	1.25	0.04	4.21	0.52	0.15	0.2	6.52	0.66	13.3	1.64	0.81	0.5
Shipyard	1.75	0.04	4.17	0.49	0.16	0.21	7.17	0.34	13.5	1.69	0.82	0.51
Shipyard	2.25	0.04	3.82	0.49	0.15	0.2	6.67	0.31	13	1.63	0.81	0.48
Shipyard	2.75	0.04	3.97	0.5	0.16	0.2	7.31	0.37	13.7	1.73	0.85	0.5
Shipyard	3.25	0.04	4.53	0.57	0.17	0.23	7.74	0.67	15.2	1.83	0.88	0.54
Shipyard	3.75	0.03	4.69	0.58	0.16	0.2	7.94	0.29	13.6	1.74	0.85	0.51
Shipyard	4.25	0.03	4.16	0.45	0.13	0.17	5.93	0.27	10.7	1.4	0.69	0.41
Shipyard	4.75	0.03	5.31	0.53	0.14	0.19	7.03	0.32	12	1.66	0.8	0.48
Shipyard	5.25	0.03	5.47	0.44	0.15	0.17	6.93	0.32	11.4	1.56	0.77	0.46
Shipyard	5.75	0.04	5.52	0.57	0.16	0.23	7.19	0.42	13.3	1.68	0.84	0.51
Shipyard	6.25	0.04	5.54	0.69	0.18	0.25	7.76	0.47	15.1	1.91	0.92	0.57
Shipyard	6.75	0.04	5.23	0.62	0.18	0.22	7.27	0.57	15.4	1.97	0.97	0.58
Shipyard	7.25	0.04	5.47	0.64	0.18	0.26	7.91	0.57	16.8	2.18	1.06	0.63
Shipyard	7.75	0.04	5.96	0.66	0.18	0.24	7.88	0.68	16	2.06	1.03	0.61
Shipyard	8.25	0.04	5.75	0.63	0.21	0.26	7.79	0.37	16.2	2.07	1.04	0.61
Shipyard	8.75	0.05	5.43	0.65	0.2	0.27	7.62	0.8	16.7	2.09	1	0.63
Shipyard	9.25	0.05	5.17	0.68	0.21	0.28	8.18	0.51	17.4	2.24	1.08	0.66
Shipyard	9.75	0.06	4.83	0.71	0.22	0.31	8.69	0.6	18.6	2.36	1.14	0.7
Shipyard	10.25	0.06	4.58	0.75	0.23	0.33	8.76	0.68	19.3	2.44	1.17	0.73
Shipyard	10.75	0.06	4.78	0.69	0.23	0.33	9.1	0.63	19.2	2.44	1.19	0.72
Shipyard	11.25	0.06	4.76	0.74	0.22	0.32	9.25	0.65	19.4	2.47	1.21	0.75
Shipyard	11.75	0.06	4.85	0.74	0.22	0.32	9.11	0.64	18.6	2.54	1.23	0.74
Shipyard	12.25	0.05	4.92	0.72	0.22	0.3	9.23	0.59	18.7	2.5	1.23	0.74
Shipyard	12.75	0.06	5.25	0.78	0.24	0.34	9.27	0.87	20.2	2.68	1.3	0.77
Shipyard	13.25	0.06	5.77	0.82	0.25	0.36	9.53	0.72	21.1	2.82	1.34	0.81
Shipyard	13.75	0.05	6.66	0.74	0.24	0.34	10.6	0.6	19.5	2.88	1.41	0.84
Shipyard	14.25	0.06	5.5	0.77	0.24	0.34	10.8	0.9	20.4	2.94	1.42	0.83
Shipyard	14.75	0.07	3.94	0.73	0.25	0.39	10.1	0.95	22.5	2.78	1.33	0.8

Shipyard	15.25	0.07	3.94	0.81	0.26	0.4	10.2	0.98	22.8	2.85	1.36	0.84
Shipyard	15.75	0.07	4.64	0.8	0.24	0.38	11	0.8	21.9	2.98	1.48	0.87
Shipyard	16.25	0.07	4.77	0.74	0.24	0.36	10.5	0.83	21.9	2.85	1.38	0.82
Shipyard	16.75	0.06	4.72	0.73	0.25	0.35	10.2	0.83	21.4	2.86	1.37	0.84
Shipyard	17.25	0.06	5.14	0.81	0.25	0.34	10.6	0.8	21.5	2.67	1.31	0.78
Shipyard	17.75	0.07	4.81	0.81	0.25	0.34	9.86	0.88	22.1	2.72	1.29	0.8
Shipyard	18.25	0.07	4.58	0.84	0.26	0.33	9.57	0.91	22.4	2.74	1.31	0.82
Shipyard	18.75	0.06	4.85	0.79	0.25	0.35	9.42	0.83	21.7	2.76	1.32	0.82
Shipyard	19.25	0.06	5.94	0.85	0.24	0.36	10.4	0.7	21.7	2.85	1.38	0.84
Shipyard	19.75	0.06	6.33	0.73	0.24	0.36	10.4	0.7	21.4	2.86	1.37	0.83
Shipyard	20.5	0.14	7.93	0.83	0.24	0.35	12.2	0.46	23.5	2.71	1.35	0.8
Shipyard	21.5	0.15	6.69	0.87	0.25	0.34	11.2	0.67	24.8	2.87	1.38	0.83
Shipyard	22.5	0.14	5.89	0.87	0.25	0.35	10.6	0.57	24.3	2.79	1.36	0.82
Shipyard	23.5	0.15	7.91	0.88	0.24	0.36	13.4	0.63	24.6	2.94	1.45	0.86
Shipyard	24.5	0.16	12.5	1	0.22	0.4	20.5	0.28	23.1	3.04	1.56	0.85
Shipyard	25.5	0.13	10.3	0.92	0.24	0.34	14.2	0.42	23.8	2.8	1.38	0.81
Shipyard	26.5	0.13	11.7	0.78	0.2	0.28	10.8	0.39	19.5	2.34	1.16	0.69
Shipyard	27.5	0.14	9.44	0.8	0.22	0.34	11	0.49	22.9	2.54	1.26	0.75
Shipyard	28.5	0.13	7.25	0.82	0.22	0.38	10.6	0.56	23.7	2.64	1.31	0.78
Shipyard	29.5	0.13	6.98	0.85	0.24	0.36	11	0.65	25	2.82	1.4	0.82
Shipyard	30.5	0.14	7.11	0.82	0.22	0.35	11.4	0.43	22.6	2.81	1.38	0.81
Shipyard	31.5	0.13	7.16	0.85	0.23	0.35	11.5	0.41	23.3	2.86	1.39	0.82
Shipyard	32.5	0.13	8.24	0.88	0.22	0.33	11.2	0.3	22.2	2.75	1.36	0.8
Shipyard	33.5	0.12	9.85	0.87	0.22	0.34	11.6	0.24	21.8	2.66	1.31	0.76
Shipyard	34.5	0.12	9.94	0.91	0.22	0.37	11.6	0.25	23.1	2.74	1.36	0.78
Shipyard	35.5	0.13	8.31	0.82	0.22	0.37	11	0.3	23.2	2.71	1.33	0.79
Shipyard	36.5	0.15	8.29	0.9	0.22	0.33	10.6	0.27	22.7	2.74	1.32	0.79
Shipyard	37.5	0.14	7.22	0.67	0.23	0.3	10.1	0.28	20.7	2.48	1.2	0.7
Shipyard	38.5	0.13	6.11	0.7	0.22	0.31	10.2	0.41	21.1	2.51	1.23	0.71
Shipyard	39.5	0.13	5.94	0.76	0.22	0.31	10.3	0.38	20.8	2.62	1.28	0.72

Table B.4 Partial digestion metal concentrations Ga-Pb204 for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Ga ICP MS Partial mg/kg	Gd ICP MS Partial mg/kg	Ge ICP MS Partial mg/kg	Hf ICP MS Partial mg/kg	Hg ICP MS Partial mg/kg	Ho ICP MS Partial mg/kg	Mo ICP MS Partial mg/kg	Nb ICP MS Partial mg/kg	Nd ICP MS Partial mg/kg	Ni ICP MS Partial mg/kg	Pb204 ICP MS Partial mg/kg
NE20	0.25	0.38	0.42	0.01	0.12	0.08	0.09	10.5	0.49	1.51	12.7	0.061
NE20	0.75	0.23	0.23	0.01	0.07	0.09	0.04	2.98	0.21	1.12	13.9	0.059
NE20	1.25	0.19	0.2	0.01	0.06	0.08	0.03	2.41	0.13	0.9	12.9	0.059
NE20	1.75	0.19	0.18	<0.01	0.07	0.08	0.02	2.05	0.12	0.82	11.1	0.061
NE20	2.25	0.17	0.16	<0.01	0.06	0.1	0.02	1.57	0.1	0.75	9.77	0.056
NE20	2.75	0.11	0.14	<0.01	0.06	0.08	0.02	1.3	0.08	0.66	8.59	0.038
NE20	3.25	0.14	0.15	<0.01	0.06	0.06	0.02	1.34	0.07	0.64	9.64	0.029
NE20	3.75	0.12	0.14	<0.01	0.05	0.05	0.02	1.09	0.07	0.63	9.24	0.028
NE20	4.25	0.1	0.14	<0.01	0.03	0.05	0.02	0.88	0.05	0.61	9.02	0.014
NE20	4.75	0.07	0.11	<0.01	0.02	0.04	0.01	0.76	0.04	0.51	8.08	0.011
NE20	5.25	0.04	0.09	<0.01	0.02	0.03	<0.01	0.61	0.03	0.4	6.76	0.008
NE20	5.75	0.09	0.12	<0.01	0.02	0.03	0.01	0.96	0.04	0.56	8.3	0.01
NE20	6.25	0.09	0.14	<0.01	0.03	0.03	0.02	1.33	0.05	0.65	7.45	0.013
NE20	6.75	0.1	0.14	<0.01	0.03	0.04	0.02	1.48	0.05	0.67	6.51	0.013
NE20	7.25	0.1	0.16	<0.01	0.04	0.04	0.02	1.24	0.06	0.75	7.01	0.015
NE20	7.75	0.1	0.15	<0.01	0.04	0.04	0.02	1.07	0.06	0.71	6.52	0.015
NE20	8.25	0.13	0.19	<0.01	0.04	0.06	0.02	1.03	0.06	0.86	6.87	0.018
NE20	8.75	0.11	0.18	<0.01	0.04	0.05	0.02	1.06	0.06	0.82	6.33	0.022
NE20	9.25	0.09	0.16	<0.01	0.03	0.04	0.02	1.06	0.05	0.71	5.82	0.018
NE20	9.75	0.1	0.15	<0.01	0.08	0.04	0.02	0.88	0.06	0.75	5.34	0.019
NE20	10.25	0.14	0.18	<0.01	0.05	0.06	0.02	0.97	0.06	0.84	6.6	0.018
NE20	10.75	0.04	0.14	<0.01	0.03	0.04	0.01	0.85	0.04	0.69	5.49	0.018
NE20	11.25	0.04	0.15	<0.01	0.03	0.05	0.02	0.98	0.05	0.7	5.15	0.016
NE20	11.75	0.07	0.12	<0.01	0.03	0.03	0.01	0.68	0.04	0.52	3.93	0.01
NE20	12.25	0.12	0.17	<0.01	0.05	0.05	0.02	0.96	0.06	0.8	6.25	0.015
NE20	12.75	0.08	0.13	<0.01	0.04	0.04	0.02	0.7	0.05	0.65	4.97	0.012

NE20	13.25	0.12	0.18	<0.01	0.04	0.05	0.02	0.87	0.06	0.82	6.43	0.014
NE20	13.75	0.06	0.13	<0.01	0.03	0.04	0.02	0.59	0.04	0.6	4.63	0.01
NE20	14.25	0.13	0.19	<0.01	0.05	0.07	0.03	1.02	0.06	0.89	6.78	0.016
NE20	14.75	0.05	0.12	<0.01	0.03	0.05	0.01	0.61	0.04	0.56	4.1	0.01
NE20	15.25	0.07	0.14	<0.01	0.04	0.05	0.02	0.76	0.05	0.69	5.2	0.013
NE20	15.75	0.09	0.15	<0.01	0.04	0.03	0.02	0.72	0.05	0.73	5.6	0.013
NE20	16.25	0.08	0.2	<0.01	0.05	0.06	0.03	0.6	0.07	0.67	5.05	0.012
NE20	16.75	0.04	0.17	<0.01	0.02	0.05	0.02	0.68	0.05	0.82	6.17	0.018
NE20	17.25	0.1	0.17	<0.01	0.04	0.06	0.02	0.8	0.06	0.8	6	0.015
NE20	17.75	0.06	0.14	<0.01	0.04	0.04	0.02	0.64	0.04	0.59	4.55	0.011
NE20	18.25	0.05	0.16	<0.01	0.03	0.06	0.02	0.87	0.05	0.81	6.41	0.017
NE20	18.75	0.08	0.11	<0.01	0.19	0.06	0.02	0.6	0.71	0.54	4.28	0.014
NE20	19.25	0.09	0.13	<0.01	0.1	0.06	0.02	0.69	0.2	0.58	4.87	0.011
NE20	19.75	0.09	0.12	<0.01	0.09	0.05	0.02	0.73	0.13	0.62	5.01	0.012
NE20	20.5	0.17	0.19	<0.01	0.1	0.09	0.03	1.03	0.13	0.89	7.43	0.016
NE20	21.5	0.11	0.16	<0.01	0.08	0.04	0.02	0.8	0.09	0.75	5.88	0.016
NE20	22.5	0.12	0.17	<0.01	0.08	0.04	0.03	0.87	0.09	0.76	6.27	0.013
NE20	23.5	0.16	0.19	<0.01	0.08	0.03	0.03	1.02	0.09	0.87	7.99	0.015
NE20	24.5	0.13	0.18	<0.01	0.07	0.04	0.03	0.91	0.08	0.84	7.47	0.015
NE20	25.5	0.08	0.12	<0.01	0.04	0.02	0.02	0.6	0.06	0.57	5.01	0.011
NE20	26.5	0.14	0.19	<0.01	0.06	0.02	0.03	0.9	0.08	0.87	7.04	0.015
NE20	27.5	0.12	0.17	<0.01	0.05	0.01	0.03	0.75	0.07	0.8	6.86	0.015
NE20	28.5	0.12	0.15	<0.01	0.04	0.02	0.02	0.77	0.06	0.76	7.12	0.013
NE20	29.5	0.11	0.14	<0.01	0.04	0.02	0.02	0.78	0.06	0.65	5.96	0.011
NE20	30.5	0.12	0.13	<0.01	0.05	0.03	0.02	1.15	0.07	0.66	6.88	0.011
NE20	31.5	0.08	0.12	<0.01	0.03	0.02	0.02	0.91	0.05	0.52	5.57	0.007
NE20	32.5	0.13	0.13	<0.01	0.04	0.04	0.02	1.03	0.07	0.63	6.96	0.01
NE20	33.5	0.07	0.11	<0.01	0.02	0.02	0.01	0.74	0.04	0.49	5.33	0.007
NE20	34.5	0.08	0.12	<0.01	0.03	0.02	0.02	0.91	0.04	0.62	7.14	0.009
NE20	35.5	0.11	0.14	<0.01	0.03	0.01	0.02	0.94	0.05	0.71	7.04	0.011
NE20	36.5	0.14	0.17	<0.01	0.09	0.04	0.02	1.29	0.06	0.81	8.03	0.02
NE20	37.5	0.07	0.1	<0.01	0.03	0.02	0.01	0.9	0.04	0.46	5.58	0.009

NE20	38.5	0.09	0.13	<0.01	0.04	0.02	0.02	1.2	0.05	0.57	7.8	0.01
NE20	39.5	0.09	0.12	<0.01	0.03	0.02	0.02	0.98	0.04	0.56	7.99	0.01
NE20	40.5	0.07	0.11	<0.01	0.02	0.02	0.02	0.92	0.04	0.52	7.67	0.009
NE20	41.5	0.06	0.1	<0.01	0.02	0.02	0.01	1.07	0.03	0.46	8.06	0.008
NE20	42.5	0.04	0.07	<0.01	0.02	<0.01	0.01	0.73	0.02	0.35	8.44	0.004
NE20	43.5	0.02	0.07	<0.01	0.02	0.02	<0.01	0.97	0.02	0.3	8.15	0.003
Isadore's	0.25	2.13	2.39	<0.01	0.22	0.14	0.37	0.88	0.17	11.7	19.6	0.167
Isadore's	0.75	2.31	2.44	0.01	0.22	0.09	0.4	0.7	0.13	12	20.3	0.174
Isadore's	1.25	2.32	2.52	0.01	0.24	0.08	0.42	0.66	0.12	12.2	21.5	0.181
Isadore's	1.75	2.21	2.55	<0.01	0.21	0.08	0.42	0.56	0.11	12	20.3	0.179
Isadore's	2.25	2.36	2.69	<0.01	0.21	0.09	0.44	0.61	0.12	13	22	0.184
Isadore's	2.75	2.24	2.58	<0.01	0.21	0.08	0.43	0.65	0.11	12.5	20.9	0.18
Isadore's	3.25	2.33	2.7	<0.01	0.22	0.07	0.44	0.63	0.12	12.9	21.5	0.186
Isadore's	3.75	2.26	2.62	<0.01	0.21	0.08	0.44	0.63	0.11	12.9	21.3	0.178
Isadore's	4.25	2.29	2.68	<0.01	0.21	0.07	0.44	0.63	0.11	13	21.1	0.184
Isadore's	4.75	2.41	2.85	<0.01	0.24	0.07	0.47	0.67	0.11	13.7	22.7	0.185
Isadore's	5.25	2.45	2.8	<0.01	0.25	0.07	0.47	0.7	0.1	13.8	23.1	0.185
Isadore's	5.75	2.5	2.93	<0.01	0.26	0.08	0.49	0.74	0.08	14.1	24.2	0.192
Isadore's	6.25	2.47	2.95	<0.01	0.26	0.08	0.49	0.68	0.08	14.1	24.4	0.192
Isadore's	6.75	2.5	3.04	<0.01	0.25	0.08	0.51	0.72	0.07	14.5	24.9	0.192
Isadore's	7.25	2.41	2.96	<0.01	0.25	0.07	0.5	0.73	0.07	14.3	24.6	0.19
Isadore's	7.75	2.36	2.83	<0.01	0.24	0.07	0.48	0.72	0.06	13.8	23.7	0.181
Isadore's	8.25	2.45	2.92	<0.01	0.25	0.07	0.5	0.79	0.07	14.4	25	0.186
Isadore's	8.75	2.41	2.98	<0.01	0.24	0.07	0.5	0.82	0.06	14.2	25.5	0.189
Isadore's	9.25	2.44	2.96	<0.01	0.25	0.07	0.5	0.79	0.07	14.3	25	0.187
Isadore's	9.75	2.55	3	<0.01	0.26	0.07	0.49	0.92	0.07	14.2	25.8	0.187
Isadore's	10.25	2.47	3.05	<0.01	0.26	0.07	0.49	0.89	0.08	14.3	25.7	0.194
Isadore's	10.75	2.44	2.86	<0.01	0.24	0.07	0.48	0.96	0.09	13.8	24.8	0.187
Isadore's	11.25	2.03	2.48	<0.01	0.19	0.07	0.41	1.29	0.11	11.8	22.8	0.162
Isadore's	11.75	1.08	1.36	<0.01	0.08	0.04	0.24	0.8	0.1	6.31	15.8	0.099
Isadore's	12.25	0.87	1.05	0.01	0.1	0.04	0.16	0.65	0.08	4.75	13.8	0.077
Isadore's	12.75	0.9	1.07	0.01	0.07	0.04	0.18	0.8	0.1	5.06	13.9	0.09

Isadore's	13.25	1.31	1.53	0.02	0.19	0.06	0.24	1.12	0.12	7.11	18.5	0.127
Isadore's	13.75	1.47	1.68	0.03	0.27	0.06	0.29	1.31	0.14	7.86	20	0.141
Isadore's	14.25	1.71	2.05	0.02	0.25	0.08	0.35	1.52	0.12	9.7	21.3	0.165
Isadore's	14.75	2.28	2.73	<0.01	0.25	0.08	0.46	1.24	0.11	13.1	23.9	0.203
Isadore's	15.25	2.54	2.89	<0.01	0.25	0.08	0.49	0.86	0.08	13.9	24.9	0.206
Isadore's	15.75	2.41	2.96	<0.01	0.25	0.08	0.51	0.84	0.1	14.2	22.5	0.216
Isadore's	16.25	2.37	2.94	<0.01	0.25	0.08	0.48	0.93	0.11	13.9	22.3	0.219
Isadore's	16.75	2.31	2.87	<0.01	0.23	0.08	0.48	1.02	0.11	14.1	22.5	0.214
Isadore's	17.25	2.39	3.07	<0.01	0.24	0.08	0.51	1.05	0.1	14.6	23.5	0.226
Isadore's	17.75	2.41	3.07	<0.01	0.27	0.08	0.51	1	0.09	14.8	24.3	0.218
Isadore's	18.25	2.28	3.06	<0.01	0.26	0.07	0.51	0.94	0.08	14.8	23.8	0.195
Isadore's	18.75	2.22	2.99	<0.01	0.3	0.08	0.5	0.98	0.09	14.4	23.5	0.195
Isadore's	19.25	2.28	2.98	<0.01	0.32	0.07	0.51	1.54	0.13	14.3	23.7	0.206
Isadore's	19.75	2.37	2.89	<0.01	0.31	0.07	0.48	1.18	0.12	13.7	23.9	0.211
Isadore's	20.5	2.76	2.83	<0.01	0.28	0.06	0.46	0.83	0.18	12.5	27.7	0.232
Isadore's	21.5	3.03	3.05	<0.01	0.3	0.06	0.49	0.84	0.14	14.1	30.8	0.251
Isadore's	22.5	2.76	2.97	<0.01	0.31	0.06	0.48	1.01	0.16	13.4	28.1	0.251
Isadore's	23.5	2.75	2.96	<0.01	0.32	0.06	0.5	1.28	0.2	13.2	27	0.236
Isadore's	24.5	2.77	3.03	<0.01	0.3	0.06	0.5	1.1	0.15	13.7	28.8	0.227
Isadore's	25.5	2.82	3.13	<0.01	0.32	0.05	0.51	1	0.12	14.1	29.5	0.231
Isadore's	26.5	2.9	3.25	<0.01	0.32	0.05	0.54	1.3	0.12	14.8	30.4	0.236
Isadore's	27.5	2.67	2.99	<0.01	0.3	0.06	0.5	1.12	0.16	13.5	27.2	0.216
Isadore's	28.5	2.74	2.93	<0.01	0.31	0.06	0.49	0.93	0.2	13.6	26	0.233
Isadore's	29.5	2.58	2.85	<0.01	0.3	0.06	0.46	1.01	0.2	13	24.8	0.218
Isadore's	30.5	2.1	2.44	<0.01	0.27	0.06	0.41	1.18	0.22	11	21.7	0.186
Isadore's	31.5	2.3	2.75	<0.01	0.26	0.06	0.45	0.9	0.17	12.7	23.9	0.211
Isadore's	32.5	2.16	2.71	<0.01	0.25	0.05	0.45	0.84	0.15	12.6	22.8	0.183
Isadore's	33.5	1.52	1.85	<0.01	0.15	0.03	0.31	1.15	0.14	8.4	19.4	0.128
Isadore's	34.5	2.44	2.78	<0.01	0.3	0.05	0.46	0.88	0.16	13	23.6	0.208
Isadore's	35.5	2.7	3.1	<0.01	0.34	0.05	0.5	0.87	0.16	14.7	25.2	0.23
Isadore's	36.5	2.54	2.98	<0.01	0.3	0.05	0.49	0.9	0.17	13.8	24.1	0.218
Isadore's	37.5	2.57	2.99	<0.01	0.3	0.06	0.5	1.05	0.18	14	25.6	0.216

Isadore's	38.5	2.5	3.27	<0.01	0.32	0.06	0.55	1.23	0.15	15.2	25.3	0.225
Isadore's	39.5	2.61	3.52	<0.01	0.33	0.06	0.59	1.02	0.08	16.6	28.2	0.244
Shipyard	0.25	1.49	1.88	<0.01	0.13	0.08	0.33	1.5	0.15	9.84	19.8	0.173
Shipyard	0.75	1.42	1.92	<0.01	0.17	0.09	0.32	1.46	0.16	9.3	20.4	0.146
Shipyard	1.25	1.4	1.84	<0.01	0.21	0.07	0.31	1.39	0.15	9.11	19.9	0.138
Shipyard	1.75	1.5	1.95	<0.01	0.25	0.08	0.32	1.46	0.18	9.35	21.6	0.147
Shipyard	2.25	1.33	1.85	<0.01	0.22	0.07	0.3	1.44	0.16	8.87	20.2	0.136
Shipyard	2.75	1.44	1.94	<0.01	0.25	0.08	0.31	1.51	0.17	9.28	21	0.142
Shipyard	3.25	1.6	2.01	<0.01	0.23	0.08	0.34	1.95	0.18	10.2	22.5	0.149
Shipyard	3.75	1.47	1.96	<0.01	0.35	0.07	0.32	1.96	0.22	9.54	22.2	0.144
Shipyard	4.25	0.99	1.58	<0.01	0.26	0.07	0.26	1.81	0.15	7.68	17.4	0.114
Shipyard	4.75	1.33	1.85	<0.01	0.34	0.06	0.31	2.24	0.21	9.12	20.6	0.132
Shipyard	5.25	1.17	1.77	<0.01	0.32	0.06	0.29	2.23	0.21	8.5	20.2	0.124
Shipyard	5.75	1.29	1.89	<0.01	0.21	0.06	0.32	2.31	0.2	9.56	22	0.129
Shipyard	6.25	1.48	2.12	<0.01	0.23	0.07	0.34	2.32	0.26	10.5	23	0.149
Shipyard	6.75	1.55	2.2	<0.01	0.25	0.07	0.36	1.82	0.21	10.8	22	0.154
Shipyard	7.25	1.7	2.4	<0.01	0.24	0.06	0.4	1.81	0.24	11.7	23.2	0.169
Shipyard	7.75	1.62	2.26	<0.01	0.22	0.08	0.38	1.83	0.22	11	23.1	0.166
Shipyard	8.25	1.86	2.35	<0.01	0.35	0.08	0.39	1.64	0.23	11.4	24.9	0.182
Shipyard	8.75	1.82	2.39	<0.01	0.2	0.08	0.38	1.6	0.17	12.1	24.2	0.176
Shipyard	9.25	2.18	2.51	<0.01	0.26	0.06	0.41	1.3	0.18	12.3	26	0.201
Shipyard	9.75	2.33	2.64	<0.01	0.26	0.05	0.44	1.25	0.17	13.1	27.1	0.209
Shipyard	10.25	2.38	2.73	<0.01	0.24	0.07	0.44	1.25	0.17	13.5	27.3	0.217
Shipyard	10.75	2.37	2.76	<0.01	0.25	0.07	0.45	1.28	0.16	13.4	27	0.214
Shipyard	11.25	2.33	2.81	<0.01	0.24	0.06	0.46	1.29	0.17	13.9	27.8	0.216
Shipyard	11.75	2.19	2.82	<0.01	0.27	0.07	0.46	1.1	0.16	14	28.1	0.21
Shipyard	12.25	2.16	2.85	<0.01	0.25	0.06	0.47	1.15	0.16	13.9	28.4	0.21
Shipyard	12.75	2.36	3	<0.01	0.33	0.07	0.5	1.07	0.16	14.6	29	0.225
Shipyard	13.25	2.51	3.07	<0.01	0.32	0.08	0.52	1.29	0.19	15.3	29.8	0.235
Shipyard	13.75	2.22	3.23	<0.01	0.31	0.08	0.54	1.46	0.2	15.7	29	0.219
Shipyard	14.25	2.33	3.19	<0.01	0.28	0.07	0.54	1.27	0.16	15.5	27.6	0.219
Shipyard	14.75	2.64	3.03	<0.01	0.27	0.08	0.5	0.96	0.1	15.1	26.7	0.226

Shipyard	15.25	2.61	3.18	<0.01	0.29	0.07	0.52	1.01	0.1	15.4	26.3	0.226
Shipyard	15.75	2.49	3.31	<0.01	0.32	0.07	0.55	1.05	0.14	16.1	26.4	0.223
Shipyard	16.25	2.52	3.19	<0.01	0.26	0.06	0.52	1.03	0.13	15.8	25.6	0.224
Shipyard	16.75	2.54	3.12	<0.01	0.28	0.07	0.53	1.11	0.14	15.8	24.7	0.222
Shipyard	17.25	2.54	3.05	<0.01	0.3	0.08	0.5	1.04	0.14	15	25.1	0.215
Shipyard	17.75	2.68	3.1	<0.01	0.28	0.08	0.5	1.01	0.14	15.2	25.1	0.22
Shipyard	18.25	2.79	3.11	<0.01	0.29	0.07	0.5	0.95	0.13	15.6	25.2	0.21
Shipyard	18.75	2.6	3.15	<0.01	0.28	0.07	0.5	0.94	0.13	15.4	24.8	0.217
Shipyard	19.25	2.5	3.18	<0.01	0.31	0.08	0.52	0.99	0.17	15.8	25.2	0.225
Shipyard	19.75	2.48	3.16	<0.01	0.31	0.08	0.52	0.98	0.16	15.4	24.9	0.218
Shipyard	20.5	2.44	3.04	<0.01	0.36	0.06	0.5	1.04	0.3	14	26.7	0.22
Shipyard	21.5	2.67	3.22	<0.01	0.39	0.06	0.52	1.04	0.28	14.8	27.1	0.228
Shipyard	22.5	2.64	3.13	<0.01	0.36	0.06	0.51	0.94	0.27	14.8	26.5	0.22
Shipyard	23.5	2.65	3.24	<0.01	0.37	0.06	0.54	1.1	0.32	15.1	29	0.228
Shipyard	24.5	2.2	3.29	<0.01	0.52	0.08	0.58	1.37	0.42	14.5	32.8	0.216
Shipyard	25.5	2.46	3.05	<0.01	0.42	0.06	0.52	1.15	0.37	14	29	0.222
Shipyard	26.5	2.03	2.61	<0.01	0.34	0.06	0.44	1.18	0.32	12	24.5	0.166
Shipyard	27.5	2.3	2.8	<0.01	0.32	0.06	0.47	1.16	0.29	12.9	26.3	0.211
Shipyard	28.5	2.39	2.9	<0.01	0.28	0.06	0.49	1.12	0.24	13.4	26.7	0.213
Shipyard	29.5	2.56	3.11	<0.01	0.3	0.06	0.52	1.25	0.26	14.2	28.3	0.226
Shipyard	30.5	2.25	3.05	<0.01	0.36	0.06	0.51	1.07	0.27	14.3	26.2	0.206
Shipyard	31.5	2.32	3.06	<0.01	0.37	0.05	0.51	1.13	0.32	14.4	25.7	0.21
Shipyard	32.5	2.18	2.96	<0.01	0.49	0.06	0.51	1.16	0.34	14.2	25.9	0.202
Shipyard	33.5	2.06	2.86	<0.01	0.49	0.06	0.48	1.53	0.37	13.3	26.1	0.202
Shipyard	34.5	2.21	3	<0.01	0.55	0.06	0.51	1.47	0.38	14	27.4	0.209
Shipyard	35.5	2.26	2.98	<0.01	0.48	0.07	0.5	1.42	0.36	13.9	27.2	0.218
Shipyard	36.5	2.2	2.92	<0.01	0.46	0.05	0.49	1.35	0.34	13.8	26.1	0.257
Shipyard	37.5	1.92	2.8	<0.01	0.36	0.06	0.45	1.33	0.26	12.5	24	0.219
Shipyard	38.5	2.03	2.85	<0.01	0.34	0.06	0.46	1.16	0.24	12.9	24.1	0.2
Shipyard	39.5	2.08	2.9	<0.01	0.35	0.05	0.47	1.27	0.25	13.4	23.8	0.205

Table B.5 Partial digestion metal concentrations Pb206-Sn for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Pb206 ICP MS Partial mg/kg	Pb207 ICP MS Partial mg/kg	Pb208 ICP MS Partial mg/kg	PbSUM ICP MS Partial mg/kg	Pr ICP MS Partial mg/kg	Rb ICP MS Partial mg/kg	Sb ICP MS Partial mg/kg	Sc ICP MS Partial mg/kg	Se ICP MS Partial mg/kg	Sm ICP MS Partial mg/kg	Sn ICP MS Partial mg/kg
NE20	0.25	13.6	1.92	2.21	17.8	0.38	1.63	0.08	0.5	0.6	0.38	0.16
NE20	0.75	3.34	1.09	2.07	6.56	0.28	1.39	0.08	0.3	0.4	0.25	0.1
NE20	1.25	2.56	1.01	2	5.63	0.23	1.2	0.07	0.3	0.5	0.18	0.08
NE20	1.75	1.92	0.961	2.05	4.98	0.21	1.24	0.09	0.3	0.4	0.17	0.07
NE20	2.25	1.81	0.865	1.83	4.56	0.2	1.32	0.08	0.3	0.8	0.16	0.08
NE20	2.75	1.16	0.624	1.34	3.16	0.16	0.96	0.07	0.2	0.5	0.14	0.06
NE20	3.25	0.996	0.461	0.968	2.45	0.16	1.07	0.06	0.3	0.4	0.16	0.08
NE20	3.75	0.915	0.426	0.89	2.26	0.15	1.08	0.05	0.2	0.5	0.14	0.07
NE20	4.25	0.461	0.223	0.474	1.17	0.16	1.11	0.04	0.2	0.6	0.13	0.12
NE20	4.75	0.335	0.163	0.35	0.86	0.13	0.72	0.03	<0.1	0.5	0.11	0.05
NE20	5.25	0.242	0.118	0.254	0.622	0.1	0.61	0.03	<0.1	0.3	0.09	0.05
NE20	5.75	0.301	0.161	0.355	0.827	0.14	1.1	0.03	0.1	0.6	0.12	0.07
NE20	6.25	0.329	0.195	0.423	0.959	0.16	1.22	0.03	0.1	0.4	0.14	0.08
NE20	6.75	0.325	0.193	0.44	0.972	0.17	1.21	0.03	0.1	0.4	0.13	0.05
NE20	7.25	0.471	0.25	0.543	1.28	0.19	1.37	0.04	0.2	0.4	0.17	0.04
NE20	7.75	0.423	0.224	0.521	1.18	0.18	1.32	0.03	0.2	0.5	0.16	0.05
NE20	8.25	0.454	0.27	0.583	1.32	0.22	1.47	0.03	0.2	0.4	0.19	0.06
NE20	8.75	0.552	0.344	0.747	1.66	0.21	1.39	0.04	0.2	0.6	0.17	0.07
NE20	9.25	0.436	0.263	0.596	1.31	0.18	1.32	0.03	0.2	0.4	0.16	0.13
NE20	9.75	0.435	0.264	0.589	1.31	0.19	1.24	0.03	0.1	0.2	0.19	0.11
NE20	10.25	0.438	0.285	0.644	1.38	0.21	1.53	0.03	0.2	0.2	0.19	0.23
NE20	10.75	0.429	0.268	0.599	1.32	0.17	1.19	0.03	<0.1	<0.1	0.12	0.51
NE20	11.25	0.387	0.241	0.528	1.17	0.19	0.94	0.03	<0.1	<0.1	0.17	0.06
NE20	11.75	0.241	0.147	0.336	0.734	0.13	0.86	0.02	<0.1	0.2	0.12	0.04
NE20	12.25	0.381	0.233	0.52	1.15	0.21	1.43	0.03	0.2	0.4	0.17	0.05
NE20	12.75	0.3	0.177	0.397	0.886	0.16	1.12	0.02	0.1	0.3	0.14	0.08

NE20	13.25	0.384	0.23	0.502	1.13	0.21	1.38	0.02	0.2	0.3	0.18	0.04
NE20	13.75	0.252	0.163	0.374	0.8	0.15	0.96	0.02	<0.1	0.2	0.13	0.04
NE20	14.25	0.378	0.244	0.557	1.2	0.22	1.63	0.03	0.2	0.4	0.2	0.05
NE20	14.75	0.22	0.149	0.331	0.71	0.14	0.98	0.02	<0.1	0.3	0.12	0.14
NE20	15.25	0.268	0.179	0.419	0.879	0.17	1.21	0.02	0.1	0.3	0.16	0.03
NE20	15.75	0.305	0.208	0.459	0.986	0.19	1.35	0.02	0.1	0.4	0.17	2.2
NE20	16.25	0.247	0.165	0.391	0.815	0.17	1.15	0.02	0.2	0.2	0.15	0.08
NE20	16.75	0.344	0.227	0.55	1.14	0.21	1.29	0.02	<0.1	<0.1	0.18	0.12
NE20	17.25	0.293	0.201	0.472	0.982	0.2	1.38	0.02	0.2	0.3	0.17	0.15
NE20	17.75	0.217	0.148	0.354	0.731	0.15	1.01	0.02	<0.1	0.2	0.12	0.15
NE20	18.25	0.313	0.221	0.508	1.06	0.2	1.25	0.02	<0.1	<0.1	0.18	0.08
NE20	18.75	0.255	0.173	0.392	0.833	0.14	0.8	0.06	0.2	0.2	0.11	0.07
NE20	19.25	0.26	0.18	0.402	0.854	0.14	0.84	0.05	0.3	<0.1	0.14	0.25
NE20	19.75	0.258	0.183	0.418	0.871	0.15	0.9	0.04	0.3	<0.1	0.14	0.13
NE20	20.5	0.353	0.259	0.556	1.18	0.22	1.52	0.05	0.4	0.1	0.19	0.07
NE20	21.5	0.339	0.272	0.576	1.2	0.19	1.16	0.04	0.3	0.1	0.16	0.04
NE20	22.5	0.262	0.214	0.463	0.954	0.2	1.18	0.04	0.4	0.3	0.18	0.05
NE20	23.5	0.301	0.228	0.523	1.07	0.22	1.48	0.04	0.4	0.4	0.19	0.05
NE20	24.5	0.298	0.232	0.509	1.06	0.21	1.23	0.03	0.4	0.2	0.18	0.04
NE20	25.5	0.201	0.151	0.35	0.714	0.14	0.81	0.02	0.2	0.2	0.13	0.03
NE20	26.5	0.298	0.234	0.528	1.08	0.23	1.39	0.03	0.4	0.2	0.2	0.05
NE20	27.5	0.267	0.207	0.472	0.96	0.2	1.26	0.03	0.3	0.2	0.19	0.1
NE20	28.5	0.319	0.203	0.438	0.974	0.19	1.12	0.03	0.3	0.3	0.17	0.04
NE20	29.5	0.221	0.175	0.386	0.794	0.17	0.91	0.03	0.2	0.2	0.14	0.06
NE20	30.5	0.218	0.157	0.361	0.747	0.17	0.78	0.03	0.3	0.1	0.14	0.04
NE20	31.5	0.148	0.117	0.257	0.529	0.13	0.59	0.02	0.2	0.2	0.11	0.07
NE20	32.5	0.204	0.142	0.309	0.666	0.16	0.86	0.03	0.3	0.2	0.13	0.07
NE20	33.5	0.134	0.104	0.227	0.471	0.12	0.64	0.02	0.2	0.2	0.11	0.02
NE20	34.5	0.173	0.138	0.309	0.629	0.15	0.9	0.03	0.3	0.3	0.14	0.04
NE20	35.5	0.211	0.169	0.384	0.775	0.18	1.15	0.03	0.3	0.2	0.16	0.04
NE20	36.5	0.46	0.322	0.714	1.52	0.2	1.5	0.03	0.4	0.1	0.17	0.09
NE20	37.5	0.179	0.131	0.286	0.604	0.12	0.73	0.02	0.2	0.3	0.11	0.04

NE20	38.5	0.245	0.158	0.348	0.762	0.15	0.97	0.03	0.3	0.4	0.13	0.05
NE20	39.5	0.212	0.154	0.356	0.732	0.15	0.98	0.03	0.3	0.6	0.13	0.05
NE20	40.5	0.225	0.145	0.306	0.685	0.13	0.79	0.02	0.2	0.3	0.11	0.04
NE20	41.5	0.172	0.129	0.295	0.604	0.12	0.68	0.03	0.2	0.4	0.1	0.05
NE20	42.5	0.088	0.065	0.142	0.3	0.09	0.45	0.02	0.2	0.5	0.08	0.05
NE20	43.5	0.07	0.044	0.094	0.206	0.07	0.36	0.02	0.2	0.8	0.06	0.04
Isadore's	0.25	2.83	2.41	5.5	10.9	2.89	13.1	0.11	2.9	<0.1	2.58	0.34
Isadore's	0.75	2.84	2.44	5.65	11.1	2.97	12.3	0.06	3	<0.1	2.78	0.49
Isadore's	1.25	3.09	2.61	5.97	11.8	3.02	10.8	0.02	3	0.4	2.84	0.45
Isadore's	1.75	2.98	2.5	5.77	11.4	2.99	10.6	0.02	3	0.4	2.8	0.3
Isadore's	2.25	3.11	2.65	6.12	12.1	3.18	11.3	0.03	3.2	0.2	3.02	0.32
Isadore's	2.75	3.02	2.6	5.98	11.8	3.1	10.6	0.04	2.9	0.4	2.87	0.33
Isadore's	3.25	3.06	2.62	6.07	11.9	3.19	11.1	0.04	3	0.4	2.97	0.32
Isadore's	3.75	3.07	2.6	5.95	11.8	3.17	11	0.04	3	0.5	3	0.32
Isadore's	4.25	3.05	2.59	5.97	11.8	3.19	11	0.04	3.1	0.3	3	0.36
Isadore's	4.75	3.14	2.66	6.16	12.1	3.36	11.6	0.03	3.4	0.4	3.13	0.34
Isadore's	5.25	3.09	2.63	6.1	12	3.35	11.6	0.04	3.5	0.1	3.15	0.35
Isadore's	5.75	3.17	2.73	6.31	12.4	3.44	12.1	0.06	3.6	0.4	3.31	0.35
Isadore's	6.25	3.16	2.68	6.14	12.2	3.5	12.2	0.06	3.6	0.2	3.25	0.4
Isadore's	6.75	3.21	2.75	6.34	12.5	3.58	12.1	0.08	3.7	0.1	3.34	0.35
Isadore's	7.25	3.1	2.63	6.11	12	3.5	12	0.08	3.6	0.3	3.35	0.4
Isadore's	7.75	2.97	2.56	5.93	11.6	3.37	11.2	0.09	3.5	0.3	3.2	0.32
Isadore's	8.25	3.08	2.65	6.1	12	3.5	11.7	0.09	3.6	0.2	3.32	0.33
Isadore's	8.75	3.14	2.65	6.15	12.1	3.5	12	0.1	3.7	0.3	3.34	0.34
Isadore's	9.25	3.06	2.65	6.11	12	3.47	11.9	0.09	3.6	0.3	3.34	0.33
Isadore's	9.75	3.12	2.7	6.22	12.2	3.47	12.2	0.07	3.8	0.4	3.34	0.33
Isadore's	10.25	3.19	2.72	6.28	12.4	3.51	11.8	0.07	3.7	0.4	3.35	0.33
Isadore's	10.75	3.09	2.65	6.06	12	3.41	11.4	0.08	3.6	0.3	3.22	0.33
Isadore's	11.25	2.76	2.32	5.35	10.6	2.91	9.82	0.08	3	0.4	2.75	0.28
Isadore's	11.75	1.67	1.42	3.31	6.5	1.55	5.35	0.08	1.6	0.3	1.46	0.15
Isadore's	12.25	1.31	1.12	2.58	5.08	1.18	4.99	0.06	1.3	0.2	1.11	0.13
Isadore's	12.75	1.47	1.26	2.92	5.74	1.25	4.32	0.09	1.3	0.2	1.17	0.15

Isadore's	13.25	2.11	1.82	4.18	8.24	1.75	6.37	0.04	1.9	0.4	1.63	0.19
Isadore's	13.75	2.36	2.03	4.7	9.24	1.95	6.46	0.03	2.1	0.4	1.8	0.2
Isadore's	14.25	2.71	2.36	5.41	10.6	2.38	7.42	0.03	2.5	0.3	2.23	0.23
Isadore's	14.75	3.4	2.93	6.8	13.3	3.22	10.6	0.04	3.4	0.4	3.06	0.32
Isadore's	15.25	3.36	2.92	6.71	13.2	3.43	12	0.06	3.6	0.4	3.29	0.33
Isadore's	15.75	3.59	3.09	7.1	14	3.51	10.9	0.04	3.6	0.4	3.31	0.33
Isadore's	16.25	3.61	3.1	7.11	14	3.43	10.6	0.04	3.4	0.5	3.29	0.34
Isadore's	16.75	3.55	3.08	7.06	13.9	3.45	10.4	0.06	3.4	0.4	3.3	0.34
Isadore's	17.25	3.63	3.17	7.32	14.3	3.57	10.9	0.07	3.5	0.5	3.42	0.34
Isadore's	17.75	3.63	3.06	7.18	14.1	3.62	11.5	0.07	3.5	0.2	3.47	0.35
Isadore's	18.25	3.3	2.81	6.59	12.9	3.63	10.8	0.1	3.4	0.5	3.45	0.32
Isadore's	18.75	3.2	2.77	6.37	12.5	3.51	11.3	0.03	3.4	0.5	3.29	0.34
Isadore's	19.25	3.42	2.97	6.86	13.4	3.53	11.1	0.03	3.5	0.6	3.31	0.34
Isadore's	19.75	3.53	2.98	6.96	13.7	3.36	11.1	0.02	3.6	0.6	3.18	0.69
Isadore's	20.5	3.87	3.34	7.95	15.4	3.05	11.8	0.02	5.1	0.2	2.96	0.25
Isadore's	21.5	4.17	3.61	8.53	16.6	3.41	13.3	0.03	5.6	<0.1	3.36	0.34
Isadore's	22.5	4.1	3.6	8.49	16.4	3.25	12.1	0.02	5.1	<0.1	3.15	0.28
Isadore's	23.5	3.92	3.41	8.08	15.6	3.24	12.3	0.06	5	<0.1	3.14	0.33
Isadore's	24.5	3.77	3.26	7.81	15.1	3.34	12.6	0.04	5.2	<0.1	3.24	0.31
Isadore's	25.5	3.88	3.34	7.9	15.4	3.5	13.3	0.04	5.1	<0.1	3.38	0.33
Isadore's	26.5	4.01	3.46	8.24	15.9	3.6	13.6	0.04	5.4	<0.1	3.48	0.35
Isadore's	27.5	3.61	3.14	7.48	14.4	3.29	12.2	0.03	5	<0.1	3.2	0.3
Isadore's	28.5	3.82	3.33	7.91	15.3	3.3	12.9	0.04	4.9	<0.1	3.21	0.32
Isadore's	29.5	3.66	3.12	7.42	14.4	3.18	11.7	0.03	4.7	<0.1	3.06	0.28
Isadore's	30.5	3.08	2.7	6.34	12.3	2.65	9.5	0.03	3.9	<0.1	2.58	0.24
Isadore's	31.5	3.42	2.96	7.05	13.6	3.09	10.9	0.04	4.3	<0.1	3.01	0.28
Isadore's	32.5	3.11	2.72	6.42	12.4	3.05	10.6	0.04	4	<0.1	2.97	0.26
Isadore's	33.5	2.15	1.85	4.44	8.58	2.03	8.44	0.03	2.9	0.1	1.98	0.19
Isadore's	34.5	3.51	3.02	7.2	13.9	3.16	11.9	0.02	4.6	<0.1	3.05	0.27
Isadore's	35.5	3.75	3.26	7.76	15	3.56	13.4	0.03	5	<0.1	3.37	0.34
Isadore's	36.5	3.59	3.09	7.37	14.3	3.39	12.5	0.03	4.7	<0.1	3.23	0.31
Isadore's	37.5	3.68	3.16	7.46	14.5	3.4	12.6	0.04	4.7	<0.1	3.3	0.33

Isadore's	38.5	3.77	3.22	7.75	15	3.7	13.1	0.02	4.8	<0.1	3.52	0.33
Isadore's	39.5	4.03	3.5	8.33	16.1	4.03	14.6	0.05	4.9	<0.1	3.87	0.37
Shipyard	0.25	2.98	2.5	5.75	11.4	2.39	11.1	0.16	1.6	<0.1	2.26	0.51
Shipyard	0.75	2.44	2.08	4.83	9.5	2.32	9.32	0.05	2	0.3	2.12	0.4
Shipyard	1.25	2.34	1.93	4.5	8.91	2.28	8.72	0.04	1.9	0.1	2.08	0.5
Shipyard	1.75	2.52	2.08	4.84	9.58	2.34	7.26	0.03	2	0.6	2.14	0.28
Shipyard	2.25	2.3	1.95	4.52	8.92	2.19	6.61	0.04	1.8	0.4	2	0.29
Shipyard	2.75	2.41	2.02	4.69	9.27	2.3	7.38	0.03	2	0.6	2.11	0.27
Shipyard	3.25	2.5	2.13	4.96	9.74	2.48	9.58	0.07	2.3	0.3	2.33	0.35
Shipyard	3.75	2.4	2.05	4.7	9.29	2.37	6.86	0.03	2.1	0.7	2.17	0.35
Shipyard	4.25	1.93	1.65	3.8	7.49	1.9	5.31	0.02	1.6	0.4	1.75	0.19
Shipyard	4.75	2.16	1.87	4.34	8.5	2.26	6.65	0.03	1.9	0.6	2.04	0.23
Shipyard	5.25	2.07	1.8	4.11	8.1	2.11	6.28	0.04	1.7	0.5	1.92	0.78
Shipyard	5.75	2.21	1.86	4.3	8.5	2.32	7.45	0.07	1.8	0.2	2.14	0.31
Shipyard	6.25	2.46	2.14	4.87	9.62	2.56	8.32	0.07	2	0.6	2.37	0.31
Shipyard	6.75	2.57	2.23	5.12	10.1	2.62	9.12	0.05	2.1	0.4	2.48	1.2
Shipyard	7.25	2.81	2.38	5.5	10.8	2.87	9.72	0.09	2.3	0.2	2.68	0.55
Shipyard	7.75	2.7	2.34	5.35	10.6	2.66	9.89	0.06	2.2	0.3	2.58	0.28
Shipyard	8.25	3	2.56	5.97	11.7	2.83	8.26	0.02	2.6	0.8	2.62	0.36
Shipyard	8.75	2.98	2.5	5.81	11.5	2.92	10.9	0.03	2.6	0.2	2.65	0.32
Shipyard	9.25	3.3	2.85	6.62	13	3.05	9.76	0.02	3	0.4	2.8	0.27
Shipyard	9.75	3.49	3.02	7	13.7	3.24	10.5	0.02	3.3	0.6	2.98	0.3
Shipyard	10.25	3.58	3.11	7.08	14	3.36	11.2	0.02	3.4	0.6	3.11	0.79
Shipyard	10.75	3.5	3	6.96	13.7	3.32	10.9	0.02	3.4	0.6	3.1	0.31
Shipyard	11.25	3.49	3.01	7.01	13.7	3.38	11.1	0.02	3.3	0.7	3.16	0.43
Shipyard	11.75	3.47	2.98	6.93	13.6	3.44	10.7	0.01	3.2	0.5	3.12	0.33
Shipyard	12.25	3.45	2.97	6.88	13.5	3.46	10.7	0.02	3.2	0.5	3.13	0.3
Shipyard	12.75	3.73	3.23	7.36	14.5	3.64	12.8	0.01	3.6	0.7	3.31	0.33
Shipyard	13.25	3.88	3.36	7.65	15.1	3.75	12.3	0.02	3.7	0.8	3.51	0.35
Shipyard	13.75	3.65	3.13	7.21	14.2	3.85	10.9	0.02	3.5	0.7	3.52	0.38
Shipyard	14.25	3.59	3.09	7.12	14	3.84	12.2	0.02	3.6	0.7	3.59	0.35
Shipyard	14.75	3.71	3.2	7.35	14.5	3.74	12.9	0.03	3.8	0.5	3.5	0.34

Shipyard	15.25	3.72	3.19	7.4	14.5	3.81	12.9	0.04	3.9	0.6	3.6	0.35
Shipyard	15.75	3.7	3.19	7.3	14.4	3.93	11.9	0.03	3.9	0.6	3.73	0.33
Shipyard	16.25	3.71	3.22	7.38	14.5	3.89	12.4	0.03	3.8	0.6	3.64	0.34
Shipyard	16.75	3.63	3.12	7.16	14.1	3.83	12.4	0.03	3.7	0.4	3.66	0.34
Shipyard	17.25	3.56	3.06	7.12	14	3.69	12.1	0.03	3.8	0.4	3.49	0.36
Shipyard	17.75	3.67	3.14	7.25	14.3	3.76	12.8	0.04	3.8	0.3	3.48	0.36
Shipyard	18.25	3.74	3.2	7.48	14.6	3.84	13.4	0.03	3.9	0.5	3.59	0.36
Shipyard	18.75	3.6	3.09	7.18	14.1	3.77	12.3	0.03	3.7	0.4	3.52	0.34
Shipyard	19.25	3.66	3.13	7.21	14.2	3.83	11.6	0.03	3.8	0.5	3.62	0.35
Shipyard	19.75	3.61	3.11	7.15	14.1	3.83	11.7	0.03	3.7	0.7	3.59	0.34
Shipyard	20.5	3.6	3.1	7.44	14.4	3.43	10.7	0.03	4.6	0.3	3.36	0.27
Shipyard	21.5	3.78	3.25	7.7	15	3.69	12.8	0.02	4.9	0.3	3.52	0.3
Shipyard	22.5	3.69	3.19	7.59	14.7	3.64	11.8	0.02	4.8	0.2	3.41	0.28
Shipyard	23.5	3.83	3.27	7.89	15.2	3.69	12.4	0.04	4.9	0.3	3.54	0.31
Shipyard	24.5	3.65	3.17	7.5	14.5	3.46	8.4	0.04	4.6	0.6	3.43	0.25
Shipyard	25.5	3.66	3.16	7.51	14.6	3.48	10.5	0.03	4.7	0.4	3.31	0.27
Shipyard	26.5	3.07	2.44	6.02	11.7	2.93	9.75	0.03	3.8	0.4	2.76	0.23
Shipyard	27.5	3.55	3.05	7.27	14.1	3.13	10.9	0.03	4.4	0.5	3.07	0.24
Shipyard	28.5	3.53	3.01	7.18	13.9	3.22	11.3	0.03	4.4	0.3	3.18	0.23
Shipyard	29.5	3.7	3.18	7.58	14.7	3.47	11.9	0.04	4.9	0.2	3.38	0.28
Shipyard	30.5	3.44	2.96	7.06	13.7	3.43	10.2	0.02	4.4	0.4	3.32	0.24
Shipyard	31.5	3.51	3.03	7.24	14	3.54	10.1	0.04	4.5	0.2	3.48	0.26
Shipyard	32.5	3.38	2.94	6.97	13.5	3.46	9.17	0.02	4.2	0.7	3.32	0.23
Shipyard	33.5	3.35	2.88	6.86	13.3	3.25	8.09	0.04	3.8	0.7	3.15	0.25
Shipyard	34.5	3.43	2.96	7.04	13.6	3.37	8.23	0.03	4.1	0.8	3.28	0.24
Shipyard	35.5	3.42	2.91	6.97	14.3	3.42	8.42	0.03	4.1	0.7	3.31	0.23
Shipyard	36.5	4.28	3.78	8.85	17.2	3.35	8.04	0.02	3.9	0.7	3.2	0.23
Shipyard	37.5	3.81	3.3	7.84	15.2	3.12	7.98	0.02	3.5	0.4	2.94	0.26
Shipyard	38.5	3.55	3.06	7.23	14	3.15	9.18	0.03	3.8	0.1	2.96	0.29
Shipyard	39.5	3.34	2.88	6.96	13.4	3.34	8.51	0.03	3.8	<0.1	3.1	0.3

Table B.6 Partial digestion metal concentrations Ta-Zr for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Ta ICP MS Partial mg/kg	Tb ICP MS Partial mg/kg	Te ICP MS Partial mg/kg	Th ICP MS Partial mg/kg	U ICP MS Partial mg/kg	V ICP MS Partial mg/kg	W ICP MS Partial mg/kg	Y ICP MS Partial mg/kg	Yb ICP MS Partial mg/kg	Zn ICP MS Partial mg/kg	Zr ICP MS Partial mg/kg
NE20	0.25	0.05	0.09	0.08	0.76	90.8	30.3	1.7	2.13	0.18	41	4.62
NE20	0.75	0.05	0.03	0.03	0.4	6	33.6	1.2	1.05	0.09	42.3	2.82
NE20	1.25	0.04	0.03	0.02	0.32	3.77	29.7	0.9	0.85	0.07	44.4	2.37
NE20	1.75	0.04	0.02	0.02	0.28	2.15	18.5	0.8	0.8	0.06	53.9	2.53
NE20	2.25	0.04	0.02	0.02	0.28	2.06	9.1	0.8	0.76	0.06	56.1	2.48
NE20	2.75	0.03	0.02	0.02	0.22	1.14	5.3	0.6	0.67	0.05	53.4	2.33
NE20	3.25	0.03	0.02	0.03	0.22	1.35	4.5	0.6	0.7	0.05	57	2.33
NE20	3.75	0.02	0.02	0.02	0.2	1.31	3.4	0.5	0.64	0.05	48.7	2.06
NE20	4.25	0.02	0.02	0.01	0.18	0.63	2.6	0.5	0.62	0.05	39.8	1.2
NE20	4.75	0.01	0.01	<0.01	0.13	0.55	2.1	0.3	0.52	0.04	29.8	1.1
NE20	5.25	<0.01	<0.01	<0.01	0.09	0.46	1.6	0.2	0.41	0.03	22.4	0.76
NE20	5.75	0.01	0.01	0.02	0.15	0.53	1.8	0.4	0.56	0.04	28.2	0.93
NE20	6.25	0.02	0.02	0.01	0.17	0.51	2	0.3	0.63	0.04	36.6	1.13
NE20	6.75	0.02	0.02	<0.01	0.18	0.51	1.9	0.2	0.61	0.05	42.7	1.46
NE20	7.25	0.02	0.02	0.01	0.21	0.79	2.2	0.3	0.72	0.05	52.8	1.57
NE20	7.75	0.02	0.02	<0.01	0.2	0.59	2.1	0.2	0.7	0.05	55.8	1.58
NE20	8.25	0.02	0.02	0.01	0.22	0.51	2.2	0.2	0.78	0.06	66.2	1.62
NE20	8.75	0.02	0.02	0.02	0.22	0.82	2.4	0.2	0.76	0.06	77.1	1.77
NE20	9.25	0.01	0.02	0.01	0.2	0.51	2	0.2	0.65	0.05	62.4	1.51
NE20	9.75	0.01	0.02	0.01	0.32	0.61	1.9	0.4	0.62	0.05	56	3.98
NE20	10.25	0.02	0.02	0.01	0.29	0.51	2.4	0.3	0.76	0.06	73.2	2.38
NE20	10.75	0.01	0.01	<0.01	0.21	0.55	1.6	0.3	0.61	0.04	66	1.33
NE20	11.25	0.01	0.01	0.01	0.2	0.52	1.7	0.3	0.65	0.05	77.5	1.3
NE20	11.75	0.01	0.01	<0.01	0.12	0.28	1.5	0.1	0.47	0.04	49.3	1.27

NE20	12.25	0.02	0.02	<0.01	0.22	0.39	2.1	0.2	0.76	0.06	80.8	2.07
NE20	12.75	0.01	0.02	0.01	0.17	0.37	1.6	0.2	0.6	0.04	65.3	1.47
NE20	13.25	0.01	0.02	0.01	0.21	0.5	1.9	0.2	0.78	0.06	79.6	1.69
NE20	13.75	<0.01	0.02	0.01	0.14	0.25	1.3	<0.1	0.56	0.04	54.3	1.19
NE20	14.25	0.01	0.03	0.01	0.23	0.61	1.8	0.2	0.86	0.07	87	1.77
NE20	14.75	<0.01	0.01	<0.01	0.13	0.27	1.1	<0.1	0.51	0.04	54.8	1.17
NE20	15.25	<0.01	0.02	<0.01	0.18	0.22	1.3	0.1	0.64	0.05	65	1.47
NE20	15.75	0.01	0.02	<0.01	0.19	0.32	1.3	0.1	0.68	0.06	73.1	1.5
NE20	16.25	0.01	0.02	0.01	0.17	0.2	1.3	0.1	0.62	0.07	62.2	1.4
NE20	16.75	<0.01	0.02	0.02	0.2	0.29	1.3	0.2	0.77	0.06	86.7	1.17
NE20	17.25	0.01	0.02	<0.01	0.21	0.28	1.5	0.1	0.76	0.06	79.7	1.75
NE20	17.75	<0.01	0.02	0.01	0.14	0.2	1.1	<0.1	0.55	0.04	59.8	1.34
NE20	18.25	0.01	0.02	0.02	0.2	0.54	1.2	0.1	0.74	0.06	80.2	1.14
NE20	18.75	0.06	0.01	<0.01	0.27	0.31	1	0.4	0.46	0.05	54	3.04
NE20	19.25	0.05	0.02	<0.01	0.22	0.28	1.1	0.4	0.56	0.05	59.8	2.12
NE20	19.75	0.04	0.02	<0.01	0.2	0.29	1.2	0.4	0.58	0.05	60.6	2.43
NE20	20.5	0.04	0.03	<0.01	0.26	0.4	1.8	0.3	0.81	0.07	83.2	2.89
NE20	21.5	0.03	0.02	<0.01	0.21	0.24	1.3	0.3	0.68	0.06	66	2.26
NE20	22.5	0.03	0.02	<0.01	0.21	0.22	1.4	0.3	0.73	0.07	73	2.5
NE20	23.5	0.02	0.03	0.01	0.25	0.24	1.8	0.3	0.8	0.07	87.4	2.67
NE20	24.5	0.02	0.02	<0.01	0.25	0.24	1.8	0.2	0.8	0.06	87.5	2.63
NE20	25.5	0.01	0.02	<0.01	0.14	0.16	1.2	0.1	0.57	0.05	61.6	1.5
NE20	26.5	0.02	0.03	<0.01	0.25	0.22	1.8	0.2	0.82	0.07	81.6	2.51
NE20	27.5	0.01	0.02	<0.01	0.21	0.21	1.5	0.1	0.73	0.06	76.1	2.02
NE20	28.5	0.01	0.02	<0.01	0.18	0.35	1.4	0.2	0.7	0.06	66.5	1.71
NE20	29.5	0.01	0.02	<0.01	0.15	0.29	1.2	0.1	0.58	0.05	61.8	1.47
NE20	30.5	0.01	0.02	<0.01	0.15	0.27	1.2	0.1	0.59	0.05	59.6	1.82
NE20	31.5	<0.01	0.01	<0.01	0.09	0.15	0.9	<0.1	0.45	0.04	44.2	1.22
NE20	32.5	0.01	0.02	<0.01	0.14	0.22	1.3	0.1	0.6	0.05	53.9	1.67
NE20	33.5	<0.01	0.01	<0.01	0.09	0.13	0.9	<0.1	0.44	0.04	40.6	0.96
NE20	34.5	<0.01	0.02	<0.01	0.12	0.19	0.9	0.1	0.56	0.04	42.8	1.2
NE20	35.5	<0.01	0.02	<0.01	0.15	0.19	1.3	<0.1	0.63	0.05	46.2	1.45

NE20	36.5	<0.01	0.03	<0.01	0.51	0.62	1.7	0.2	0.77	0.06	62.5	4.62
NE20	37.5	<0.01	0.01	<0.01	0.15	0.22	0.9	0.2	0.44	0.04	42	1.66
NE20	38.5	<0.01	0.02	<0.01	0.17	0.42	1	0.3	0.57	0.05	50.6	1.84
NE20	39.5	<0.01	0.02	<0.01	0.18	0.22	1.1	0.3	0.56	0.05	50.4	2.33
NE20	40.5	<0.01	0.01	<0.01	0.13	0.22	1	0.2	0.46	0.04	44.6	1.12
NE20	41.5	<0.01	0.01	<0.01	0.12	0.22	0.8	0.2	0.4	0.03	37.3	1.05
NE20	42.5	<0.01	0.01	0.01	0.08	0.14	0.6	0.2	0.32	0.02	26.6	0.73
NE20	43.5	<0.01	<0.01	<0.01	0.07	0.17	0.5	0.1	0.27	0.02	20.7	0.63
Isadore's	0.25	0.01	0.36	0.03	3.73	1.24	18.8	0.5	9.17	0.79	69.3	10.3
Isadore's	0.75	<0.01	0.36	0.02	3.61	1.14	19.1	0.7	9.82	0.83	71.3	10.4
Isadore's	1.25	<0.01	0.38	0.02	3.75	1.96	19	0.4	10.4	0.88	76.3	11
Isadore's	1.75	<0.01	0.39	0.02	3.84	1.75	18	0.5	10.2	0.87	73.8	9.96
Isadore's	2.25	<0.01	0.4	0.02	4.12	1.29	19.2	0.4	10.8	0.94	78.1	10.4
Isadore's	2.75	<0.01	0.39	0.02	3.86	1.33	18.7	0.3	10.6	0.9	74.7	10
Isadore's	3.25	<0.01	0.4	0.02	3.98	1.22	18.8	0.3	10.7	0.91	76.3	10.1
Isadore's	3.75	<0.01	0.4	0.02	4.03	1.26	18.6	0.3	10.7	0.91	75.1	9.86
Isadore's	4.25	<0.01	0.4	0.02	4.21	1.26	18.8	0.2	10.7	0.93	75	9.8
Isadore's	4.75	<0.01	0.43	0.02	4.84	1.11	19.2	0.2	11.3	0.99	79.1	11.2
Isadore's	5.25	<0.01	0.42	0.02	5	1.26	18.8	0.2	11.4	0.97	78.4	11
Isadore's	5.75	<0.01	0.44	0.02	5.38	1.16	19.1	0.2	11.8	1.01	80.5	11.3
Isadore's	6.25	<0.01	0.45	0.03	5.3	1.31	18.7	0.2	11.9	1.03	79.4	11.4
Isadore's	6.75	<0.01	0.46	0.03	5.48	1.16	18.8	0.2	12.1	1.04	81.2	11.3
Isadore's	7.25	<0.01	0.46	0.02	5.26	1.17	18.6	0.2	12	1.01	79.8	11.2
Isadore's	7.75	<0.01	0.43	0.02	5.05	1.07	17.9	0.2	11.5	1	77.3	10.4
Isadore's	8.25	<0.01	0.45	0.02	5.27	1.08	18.8	0.2	11.9	1.03	80.9	10.7
Isadore's	8.75	<0.01	0.45	0.03	5.31	1.1	18.8	0.2	12	1.04	81.4	10.7
Isadore's	9.25	<0.01	0.45	0.03	5.28	1.08	18.8	0.1	11.6	1.02	79.8	10.7
Isadore's	9.75	<0.01	0.46	0.02	5.38	1.14	19.2	0.3	11.9	1.01	81.6	11.8
Isadore's	10.25	<0.01	0.46	0.02	5.4	1.28	18.9	0.2	11.9	1.05	80.4	11.4
Isadore's	10.75	<0.01	0.43	0.03	5.19	1.11	18.4	0.2	11.4	0.99	77	10.8
Isadore's	11.25	<0.01	0.38	0.03	4.39	1.43	18.2	0.2	10.3	0.88	65.8	9.5
Isadore's	11.75	<0.01	0.21	0.02	2.22	0.77	12.8	0.2	6.19	0.5	36.6	4.25

Isadore's	12.25	<0.01	0.15	0.01	1.9	0.63	10.8	0.2	4.43	0.36	28.3	4.37
Isadore's	12.75	<0.01	0.16	0.01	1.79	0.62	13	0.2	4.64	0.39	31.6	3.56
Isadore's	13.25	<0.01	0.23	0.03	3.08	0.89	20.6	0.2	6.63	0.55	43.1	8.32
Isadore's	13.75	<0.01	0.25	0.02	3.44	0.84	24.8	0.3	7.49	0.62	48.7	10.3
Isadore's	14.25	<0.01	0.31	0.02	4	1	26.9	0.2	8.97	0.75	55.3	10.4
Isadore's	14.75	<0.01	0.42	0.03	5.14	1.09	25.8	0.2	11.3	0.98	73.2	11.1
Isadore's	15.25	<0.01	0.44	0.03	5.55	1.07	20	0.2	11.3	1	80.2	10.6
Isadore's	15.75	<0.01	0.46	0.03	5.58	1.08	22.2	0.2	11.8	1.06	76.4	11.2
Isadore's	16.25	<0.01	0.44	0.03	5.5	1	22	0.2	11.6	1.02	75.2	11.2
Isadore's	16.75	<0.01	0.43	0.03	5.49	1.03	20.1	0.2	11.6	1.01	75	10.6
Isadore's	17.25	<0.01	0.46	0.03	5.7	1.17	20.1	0.2	12.2	1.07	77.6	11
Isadore's	17.75	<0.01	0.47	0.03	5.88	1.3	19.3	0.2	12	1.09	79.7	11.6
Isadore's	18.25	<0.01	0.48	0.03	5.61	1.2	18.1	0.2	11.8	1.07	75.4	11.2
Isadore's	18.75	<0.01	0.45	0.02	5.54	1.36	18.4	0.5	11.8	1.03	74.3	13.2
Isadore's	19.25	<0.01	0.45	0.02	5.62	1.36	19.6	0.4	12	1.05	74.8	13.8
Isadore's	19.75	<0.01	0.44	0.02	5.68	1.46	19.8	0.3	11.6	1	74.7	13.3
Isadore's	20.5	<0.01	0.41	0.04	5.63	1.1	23.9	0.4	12	0.96	87	12.1
Isadore's	21.5	<0.01	0.46	0.03	6.18	1.25	24.5	0.2	12.9	1.04	94.9	12
Isadore's	22.5	<0.01	0.44	0.03	5.76	1.18	23.5	0.2	12.4	1	88.2	12.9
Isadore's	23.5	<0.01	0.44	0.05	5.81	1.1	24.2	0.2	12.7	1.03	87.1	13.8
Isadore's	24.5	<0.01	0.46	0.04	5.94	1.16	23.8	0.1	12.9	1.06	88.9	12.7
Isadore's	25.5	<0.01	0.47	0.03	6.18	1.25	22.4	0.1	13	1.07	89.6	12.5
Isadore's	26.5	<0.01	0.49	0.03	6.41	1.36	23.2	<0.1	13.4	1.12	91.5	12.6
Isadore's	27.5	<0.01	0.46	0.04	5.72	1.14	22.8	<0.1	12.7	1.06	85.8	12.7
Isadore's	28.5	<0.01	0.44	0.04	5.85	1.02	23.2	0.1	12.1	1.02	86.6	13.2
Isadore's	29.5	<0.01	0.43	0.03	5.52	1.01	22.7	<0.1	11.9	0.98	82.9	12.9
Isadore's	30.5	<0.01	0.37	0.03	4.59	0.99	21.4	<0.1	10.9	0.86	70.6	12.1
Isadore's	31.5	<0.01	0.41	0.03	5.14	1.07	21.3	<0.1	11.4	0.97	78.7	11.5
Isadore's	32.5	<0.01	0.41	0.04	4.99	1.04	20	<0.1	11.2	0.94	71.5	11.1
Isadore's	33.5	<0.01	0.27	0.03	3.48	0.83	15.2	<0.1	9.09	0.66	48.6	7.65
Isadore's	34.5	<0.01	0.41	0.03	5.59	1.08	22	<0.1	11.9	0.98	80.1	12.7
Isadore's	35.5	<0.01	0.45	0.04	6.32	1.1	22.3	<0.1	12.5	1.09	82.5	14

Isadore's	36.5	<0.01	0.44	0.03	5.94	1.06	23.2	<0.1	12.6	1.05	81.9	13.2
Isadore's	37.5	<0.01	0.46	0.04	5.91	1.14	22.6	<0.1	12.5	1.04	85.7	12.8
Isadore's	38.5	<0.01	0.49	0.04	6.27	1.27	23	<0.1	14	1.18	86.8	13.8
Isadore's	39.5	<0.01	0.52	0.04	6.8	1.47	21.2	0.3	14.5	1.24	93.4	12.6
Shipyard	0.25	<0.01	0.29	0.03	3.28	1.67	21.3	1.2	7.39	0.67	65.3	7.1
Shipyard	0.75	<0.01	0.29	0.02	2.94	1.07	21.2	1.3	7.48	0.67	50.7	7.84
Shipyard	1.25	<0.01	0.28	0.03	2.89	1.54	20.6	1.2	7.36	0.62	49.2	9.58
Shipyard	1.75	<0.01	0.29	0.02	2.92	1.89	21.7	1.3	7.92	0.67	50.6	11.4
Shipyard	2.25	<0.01	0.28	0.03	2.64	1.38	20.8	1.2	7.45	0.65	47.9	10.1
Shipyard	2.75	<0.01	0.29	0.02	2.84	1.52	21.9	1.4	7.78	0.67	51.2	11.2
Shipyard	3.25	<0.01	0.31	0.04	3.42	1.68	25.2	1.1	8.02	0.69	78.5	11
Shipyard	3.75	<0.01	0.29	0.03	3.16	1.39	24.8	1.1	7.96	0.68	50.5	13.4
Shipyard	4.25	<0.01	0.24	0.03	2.4	1.14	20.7	0.8	6.33	0.54	39.5	10.3
Shipyard	4.75	<0.01	0.27	0.03	2.87	1.19	25.4	0.8	7.55	0.63	46.2	12.9
Shipyard	5.25	<0.01	0.26	0.03	2.63	1.26	24.8	0.9	7.28	0.6	43.3	12.4
Shipyard	5.75	<0.01	0.28	0.04	2.66	1.59	26.5	0.8	7.75	0.67	51.6	10.1
Shipyard	6.25	<0.01	0.32	0.05	2.97	1.49	28	0.7	8.5	0.73	54	10.8
Shipyard	6.75	<0.01	0.34	0.04	3.17	1.55	27.5	0.7	8.67	0.74	55.6	11.3
Shipyard	7.25	<0.01	0.36	0.04	3.4	1.42	30.2	0.5	9.43	0.83	58	11.5
Shipyard	7.75	<0.01	0.34	0.04	3.35	1.32	31.4	0.5	9.12	0.79	58.5	10.4
Shipyard	8.25	<0.01	0.35	0.03	3.84	1.23	31.4	0.6	9.4	0.8	63.5	14.6
Shipyard	8.75	<0.01	0.36	0.03	3.93	1.52	30.6	0.6	9.09	0.8	64.3	9.84
Shipyard	9.25	<0.01	0.38	0.02	4.51	0.99	32.2	0.3	9.86	0.84	67.8	11.1
Shipyard	9.75	<0.01	0.4	0.02	5.01	1.18	33.4	0.3	10.3	0.89	72.7	11.2
Shipyard	10.25	<0.01	0.41	0.02	5.17	1.21	33.5	0.3	10.7	0.93	75.8	11.1
Shipyard	10.75	<0.01	0.42	0.02	5.12	1.13	34	0.2	10.6	0.93	75.5	11
Shipyard	11.25	<0.01	0.43	0.02	5.12	1.17	35.8	0.2	11.1	0.94	74.2	11.3
Shipyard	11.75	<0.01	0.43	0.02	5.02	1.18	36.1	0.2	11.2	0.96	71.6	11.9
Shipyard	12.25	<0.01	0.43	0.02	5.07	1.22	36.6	0.2	11.3	0.95	69.3	11.4
Shipyard	12.75	<0.01	0.45	0.02	5.73	1.24	38.5	0.2	11.8	1.02	73.7	13.8
Shipyard	13.25	<0.01	0.47	0.03	5.93	1.3	40.2	0.2	12.4	1.08	77.2	14.1
Shipyard	13.75	<0.01	0.49	0.03	5.54	1.33	36.8	0.2	13.1	1.12	71.8	14.1

Shipyard	14.25	<0.01	0.49	0.03	5.78	1.35	27.8	0.2	12.8	1.12	75.4	13.2
Shipyard	14.75	<0.01	0.47	0.03	6.12	1.37	19.8	0.2	11.6	1.03	84	11.2
Shipyard	15.25	<0.01	0.49	0.02	6.26	1.29	19.6	0.2	12	1.08	83.9	12.1
Shipyard	15.75	<0.01	0.5	0.02	6.2	1.29	21.5	0.2	13	1.16	83.4	14.2
Shipyard	16.25	<0.01	0.48	0.02	6.12	1.39	19.6	0.2	12.4	1.08	83.5	12.1
Shipyard	16.75	<0.01	0.48	0.02	6.01	1.44	19.2	0.2	12.1	1.08	81.5	12.3
Shipyard	17.25	<0.01	0.46	0.02	5.92	1.39	19	0.4	11.8	1.02	81.2	13.2
Shipyard	17.75	<0.01	0.47	0.02	6.11	1.34	18.9	0.3	11.7	1	84.4	12
Shipyard	18.25	<0.01	0.48	0.02	6.33	1.35	18.7	0.3	11.8	1.02	85.9	12
Shipyard	18.75	<0.01	0.47	0.03	6.08	1.39	18.3	0.3	11.6	1.02	82.7	12.2
Shipyard	19.25	<0.01	0.48	0.02	6	1.47	19.9	0.3	12.3	1.08	81.6	13.6
Shipyard	19.75	<0.01	0.48	0.02	5.94	1.41	19.6	0.3	12.2	1.08	80.2	13.6
Shipyard	20.5	<0.01	0.46	0.02	5.21	1.34	21.9	0.2	12.3	1.07	83.3	14.4
Shipyard	21.5	<0.01	0.47	0.03	5.9	1.34	22	0.2	12.4	1.09	88.3	15.7
Shipyard	22.5	<0.01	0.46	0.03	5.65	1.32	21	0.1	12.1	1.06	86.8	14.6
Shipyard	23.5	<0.01	0.48	0.03	5.74	1.37	24	0.1	13.1	1.15	87.4	15.3
Shipyard	24.5	<0.01	0.5	0.03	5.06	1.53	26	0.1	13.9	1.27	82	19.6
Shipyard	25.5	<0.01	0.46	0.03	5.31	1.38	24.2	0.1	12.5	1.11	82.4	16.7
Shipyard	26.5	<0.01	0.39	0.03	4.38	1.11	21.2	0.1	11.1	0.95	66.3	14.2
Shipyard	27.5	<0.01	0.42	0.03	5	1.25	22.8	<0.1	11.5	0.99	79	13.4
Shipyard	28.5	<0.01	0.45	0.03	5.09	1.26	21.5	<0.1	11.9	1.03	82.8	12.2
Shipyard	29.5	<0.01	0.47	0.03	5.57	1.34	23.3	<0.1	12.6	1.1	86.4	13.2
Shipyard	30.5	<0.01	0.45	0.03	5.08	1.24	21.9	<0.1	12.5	1.09	80.1	15
Shipyard	31.5	<0.01	0.47	0.04	5.22	1.27	22.2	<0.1	12.6	1.1	81	15.6
Shipyard	32.5	<0.01	0.46	0.03	4.87	1.39	21.1	<0.1	12.1	1.1	78.6	18.1
Shipyard	33.5	<0.01	0.43	0.03	4.4	1.51	20.9	<0.1	11.8	1.03	77.2	17.8
Shipyard	34.5	<0.01	0.46	0.03	4.63	1.58	21.3	<0.1	12.1	1.09	82	19
Shipyard	35.5	<0.01	0.46	0.04	4.69	1.57	21.3	<0.1	12	1.05	81.4	17.5
Shipyard	36.5	<0.01	0.45	0.04	4.49	1.53	19.8	<0.1	11.9	1.04	80	17
Shipyard	37.5	<0.01	0.4	0.02	4.38	1.48	18.2	0.4	10.9	0.93	71.7	14.2
Shipyard	38.5	<0.01	0.42	0.01	4.8	1.28	18.5	0.2	10.9	0.97	73.2	13.7
Shipyard	39.5	<0.01	0.43	0.02	4.77	1.34	18.4	0.2	11.2	0.98	67.2	14

Table B.7 Total digestion metal concentrations Ag-Co for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Ag ICP MS Total mg/kg	Al Total mg/kg	Ba ICP Total mg/kg	Be ICP MS Total mg/kg	Bi ICP MS Total mg/kg	Ca Total mg/kg	Cd ICP MS Total mg/kg	Ce ICP Total mg/kg	Co ICP MS Total mg/kg
NE20	0.25	0.15	9050.30	273.00	0.40	1.00	93624.5	0.50	1.00	4.06
NE20	0.75	0.07	5080.87	199.00	0.20	0.30	121497.4	0.30	<1	3.57
NE20	1.25	0.06	4128.21	185.00	0.10	0.20	132217.8	0.30	<1	3.06
NE20	1.75	0.06	3704.80	178.00	0.10	0.20	135791.2	0.30	<1	2.68
NE20	2.25	0.05	3493.10	166.00	0.10	0.20	141508.8	0.30	<1	2.37
NE20	2.75	0.05	3228.47	155.00	0.20	<0.1	122926.8	0.30	<1	2.44
NE20	3.25	0.05	2910.92	163.00	0.10	<0.1	147941.0	0.30	<1	2.58
NE20	3.75	0.04	2646.29	171.00	<0.1	<0.1	171525.8	0.30	<1	2.40
NE20	4.25	0.04	2593.36	189.00	0.20	<0.1	205830.9	0.20	<1	2.37
NE20	4.75	0.04	2381.66	202.00	0.10	<0.1	232274.5	0.20	<1	2.40
NE20	5.25	0.03	2169.96	201.00	0.10	<0.1	235848.0	0.20	<1	2.24
NE20	5.75	0.04	2540.44	194.00	0.10	<0.1	232989.2	0.20	<1	2.19
NE20	6.25	0.04	3069.69	170.00	0.10	<0.1	187249.0	0.20	<1	2.24
NE20	6.75	0.05	3387.25	149.00	0.10	<0.1	142938.2	0.30	<1	2.37
NE20	7.25	0.05	3704.80	126.00	0.10	<0.1	92195.1	0.30	<1	2.24
NE20	7.75	0.05	3598.95	123.00	0.20	<0.1	80760.1	0.30	<1	2.22
NE20	8.25	0.07	3810.65	128.00	0.20	<0.1	98627.3	0.30	<1	2.28
NE20	8.75	0.07	3863.58	126.00	0.20	<0.1	87192.3	0.40	<1	2.34
NE20	9.25	0.07	3704.80	107.00	0.10	<0.1	50957.5	0.40	<1	2.40
NE20	9.75	0.06	3916.50	105.00	0.20	0.20	37449.8	0.40	<1	2.20
NE20	10.25	0.06	3810.65	108.00	0.10	<0.1	42381.2	0.40	<1	2.17
NE20	10.75	0.06	3863.58	113.00	0.10	<0.1	56960.9	0.40	<1	2.15
NE20	11.25	0.05	3863.58	112.00	0.20	<0.1	46240.5	0.40	<1	2.10
NE20	11.75	0.05	3651.88	112.00	0.20	<0.1	48956.3	0.30	<1	2.04

NE20	12.25	0.07	3598.95	108.00	0.10	<0.1	49027.8	0.40	<1	2.14
NE20	12.75	0.05	3704.80	116.00	0.10	<0.1	56889.4	0.30	<1	2.32
NE20	13.25	0.06	3598.95	116.00	0.10	<0.1	63893.4	0.40	<1	2.20
NE20	13.75	0.06	3863.58	118.00	0.20	<0.1	64465.1	0.40	<1	2.20
NE20	14.25	0.06	3916.50	117.00	0.10	<0.1	59605.2	0.40	<1	2.27
NE20	14.75	0.07	4075.28	121.00	0.20	0.10	69753.8	0.40	<1	2.38
NE20	15.25	0.06	4075.28	119.00	0.10	<0.1	61534.9	0.40	<1	2.37
NE20	15.75	0.06	4181.13	123.00	0.20	<0.1	65394.2	0.40	<1	2.43
NE20	16.25	0.06	4075.28	120.00	0.10	<0.1	64465.1	0.40	<1	2.38
NE20	16.75	0.06	4075.28	121.00	0.10	<0.1	65394.2	0.40	<1	2.42
NE20	17.25	0.08	4075.28	121.00	0.20	<0.1	66323.3	0.40	<1	2.39
NE20	17.75	0.06	3916.50	119.00	0.10	<0.1	67323.9	0.40	<1	2.34
NE20	18.25	0.06	4128.21	127.00	0.20	<0.1	75757.2	0.40	<1	2.34
NE20	18.75	0.07	4234.06	130.00	0.20	0.30	80045.4	0.40	<1	2.38
NE20	19.25	0.06	4181.13	131.00	0.10	<0.1	84333.5	0.40	<1	2.27
NE20	19.75	0.06	4181.13	133.00	0.20	<0.1	87907.0	0.40	<1	2.28
NE20	20.5	0.06	4234.06	136.00	0.10	<0.1	92909.8	0.40	<1	2.27
NE20	21.5	0.05	4128.21	136.00	0.10	<0.1	98627.3	0.30	<1	2.19
NE20	22.5	0.05	4181.13	142.00	0.20	<0.1	107203.6	0.40	<1	2.34
NE20	23.5	0.06	4181.13	141.00	0.10	<0.1	122926.8	0.40	<1	2.90
NE20	24.5	0.07	4339.91	152.00	0.20	<0.1	132217.8	0.40	<1	2.56
NE20	25.5	0.06	4392.84	148.00	0.10	<0.1	118638.7	0.40	<1	2.53
NE20	26.5	0.06	4657.46	157.00	0.10	<0.1	132932.5	0.40	<1	2.53
NE20	27.5	0.05	4551.61	168.00	0.10	<0.1	156517.3	0.40	<1	2.56
NE20	28.5	0.04	3916.50	174.00	<0.1	<0.1	175813.9	0.30	<1	2.22
NE20	29.5	0.05	3757.73	163.00	0.10	<0.1	162234.8	0.30	<1	2.06
NE20	30.5	0.05	3281.40	155.00	0.10	<0.1	161520.1	0.30	<1	1.75
NE20	31.5	0.05	3122.62	166.00	0.10	<0.1	185104.9	0.20	<1	1.64
NE20	32.5	0.04	3016.77	166.00	0.10	<0.1	175099.2	0.30	<1	1.58
NE20	33.5	0.08	2805.06	177.00	0.20	<0.1	194395.9	0.20	<1	1.59
NE20	34.5	0.04	2646.29	172.00	0.10	<0.1	199398.7	0.30	<1	1.60
NE20	35.5	0.04	3493.10	166.00	0.10	<0.1	168667.0	0.30	<1	1.85

NE20	36.5	0.06	4392.84	164.00	0.10	0.40	142223.5	0.30	<1	1.91
NE20	37.5	0.05	3228.47	161.00	0.20	<0.1	155087.9	0.20	<1	1.69
NE20	38.5	0.03	2540.44	164.00	0.10	<0.1	175813.9	0.20	<1	1.57
NE20	39.5	0.04	2699.21	185.00	0.10	<0.1	212977.8	0.30	<1	1.74
NE20	40.5	0.04	2328.73	190.00	0.10	<0.1	226557.0	0.20	<1	1.67
NE20	41.5	0.03	1958.25	203.00	<0.1	<0.1	253000.5	0.20	<1	1.67
NE20	42.5	0.02	1270.22	246.00	<0.1	<0.1	315893.3	0.20	<1	1.42
NE20	43.5	<0.02	1164.37	242.00	<0.1	<0.1	336619.4	<0.1	<1	1.23
Isadore's	0.25	0.46	59276.82	645.00	1.60	0.40	20368.7	0.40	50.00	11.60
Isadore's	0.75	0.39	65627.91	674.00	1.40	0.30	23156.0	0.30	53.00	12.50
Isadore's	1.25	0.37	65627.91	658.00	1.40	0.30	23656.3	0.30	52.00	12.40
Isadore's	1.75	0.38	65627.91	672.00	1.40	0.30	24442.4	0.40	54.00	12.80
Isadore's	2.25	0.34	69332.71	670.00	1.50	0.30	24513.9	0.40	54.00	11.40
Isadore's	2.75	0.32	65627.91	660.00	1.50	0.30	24513.9	0.40	55.00	11.20
Isadore's	3.25	0.33	65627.91	657.00	1.50	0.30	24156.5	0.40	54.00	11.30
Isadore's	3.75	0.37	66157.17	669.00	1.40	0.30	24299.5	0.30	54.00	12.90
Isadore's	4.25	0.37	68274.20	691.00	1.40	0.30	24156.5	0.40	56.00	13.00
Isadore's	4.75	0.39	68274.20	707.00	1.60	0.30	22083.9	0.40	56.00	13.70
Isadore's	5.25	0.40	68803.45	719.00	1.50	0.30	20654.6	0.40	56.00	13.80
Isadore's	5.75	0.38	70391.23	744.00	1.60	0.30	20797.5	0.40	57.00	13.80
Isadore's	6.25	0.40	67744.94	731.00	1.60	0.30	20583.1	0.40	57.00	13.20
Isadore's	6.75	0.40	68803.45	767.00	1.40	0.30	22012.5	0.40	57.00	13.90
Isadore's	7.25	0.40	69332.71	760.00	1.40	0.30	23013.0	0.40	57.00	13.80
Isadore's	7.75	0.42	69861.97	778.00	1.60	0.30	23727.7	0.40	58.00	14.00
Isadore's	8.25	0.42	68803.45	771.00	1.30	0.30	23942.1	0.30	57.00	13.80
Isadore's	8.75	0.42	69332.71	787.00	1.40	0.30	24013.6	0.40	57.00	14.30
Isadore's	9.25	0.41	69861.97	789.00	1.50	0.30	24156.5	0.40	57.00	13.90
Isadore's	9.75	0.39	69861.97	787.00	1.40	0.30	27229.7	0.40	57.00	13.90
Isadore's	10.25	0.41	67744.94	771.00	1.40	0.30	29302.3	0.40	58.00	14.00
Isadore's	10.75	0.41	67744.94	752.00	1.40	0.30	34019.3	0.40	56.00	13.50
Isadore's	11.25	0.35	62452.37	689.00	1.20	0.30	61177.5	0.40	49.00	13.20
Isadore's	11.75	0.23	42763.99	567.00	0.70	0.20	152943.8	0.20	32.00	9.17

Isadore's	12.25	0.20	35248.54	536.00	0.70	0.20	180102.1	0.20	28.00	7.40
Isadore's	12.75	0.21	39217.97	541.00	0.70	0.20	163664.2	0.20	29.00	7.55
Isadore's	13.25	0.23	41599.63	546.00	0.90	0.20	134361.9	0.20	32.00	8.26
Isadore's	13.75	0.24	44087.14	544.00	0.80	0.20	107203.6	0.30	34.00	8.83
Isadore's	14.25	0.29	52184.77	589.00	1.00	0.30	87192.3	0.30	42.00	10.40
Isadore's	14.75	0.38	67744.94	675.00	1.20	0.30	53887.7	0.30	52.00	11.70
Isadore's	15.25	0.42	73037.51	765.00	1.40	0.30	33733.4	0.40	56.00	15.00
Isadore's	15.75	0.42	70391.23	688.00	1.60	0.30	37235.4	0.40	57.00	12.80
Isadore's	16.25	0.41	71449.74	684.00	1.50	0.40	42595.6	0.40	58.00	12.90
Isadore's	16.75	0.40	67744.94	664.00	1.40	0.30	41952.3	0.40	54.00	13.20
Isadore's	17.25	0.41	70920.48	707.00	1.40	0.30	41166.2	0.40	58.00	13.90
Isadore's	17.75	0.43	73566.77	736.00	1.60	0.40	30160.0	0.40	61.00	15.10
Isadore's	18.25	0.44	69332.71	749.00	1.60	0.30	29302.3	0.40	59.00	14.90
Isadore's	18.75	0.43	66686.42	727.00	1.60	0.30	31017.6	0.40	58.00	14.80
Isadore's	19.25	0.42	65627.91	677.00	1.50	0.30	35162.8	0.40	55.00	14.70
Isadore's	19.75	0.40	67744.94	681.00	1.40	0.30	43810.5	0.40	54.00	14.10
Isadore's	20.5	0.42	77271.57	736.00	2.10	0.40	66966.5	0.50	56.00	14.00
Isadore's	21.5	0.47	79388.60	757.00	2.00	0.40	44811.1	0.50	58.00	15.80
Isadore's	22.5	0.44	78330.09	725.00	1.90	0.40	40451.5	0.50	58.00	15.00
Isadore's	23.5	0.42	74096.03	664.00	1.80	0.40	38021.5	0.50	57.00	14.70
Isadore's	24.5	0.42	76213.06	712.00	2.10	0.40	45382.9	0.50	58.00	15.10
Isadore's	25.5	0.47	77271.57	729.00	2.10	0.40	37521.3	0.50	59.00	15.80
Isadore's	26.5	0.41	78859.34	750.00	2.00	0.40	40808.8	0.50	61.00	16.10
Isadore's	27.5	0.43	75154.54	709.00	2.00	0.40	45382.9	0.50	58.00	15.00
Isadore's	28.5	0.39	75683.80	681.00	1.90	0.40	33876.3	0.40	57.00	13.90
Isadore's	29.5	0.38	71449.74	660.00	1.90	0.30	46526.4	0.40	54.00	13.30
Isadore's	30.5	0.33	60335.34	595.00	1.50	0.30	59033.5	0.40	46.00	11.80
Isadore's	31.5	0.42	68803.45	675.00	1.80	0.30	43953.5	0.50	54.00	13.50
Isadore's	32.5	0.37	63510.88	682.00	1.80	0.30	53530.3	0.40	52.00	12.40
Isadore's	33.5	0.25	45621.98	666.00	1.10	0.20	188678.4	0.30	36.00	9.47
Isadore's	34.5	0.43	73037.51	661.00	1.90	0.40	52029.5	0.40	56.00	13.10
Isadore's	35.5	0.42	82034.89	668.00	2.20	0.40	33947.8	0.40	61.00	14.60

Isadore's	36.5	0.42	74096.03	644.00	1.90	0.40	37163.9	0.40	56.00	13.00
Isadore's	37.5	0.41	73566.77	667.00	1.80	0.40	38950.6	0.40	57.00	13.90
Isadore's	38.5	0.45	77800.83	681.00	2.30	0.40	31660.8	0.40	63.00	14.90
Isadore's	39.5	0.50	83622.66	760.00	2.10	0.50	18010.2	0.50	68.00	16.30
Shipyard	0.25	0.29	41440.85	422.00	0.90	0.30	80045.4	0.30	36.00	10.00
Shipyard	0.75	0.25	45516.13	446.00	1.00	0.20	102915.5	0.20	37.00	9.48
Shipyard	1.25	0.24	45569.06	444.00	1.00	0.30	102200.8	0.20	39.00	9.90
Shipyard	1.75	0.25	45674.91	436.00	1.00	0.30	106488.9	0.30	39.00	10.10
Shipyard	2.25	0.26	48585.82	449.00	1.00	0.20	99342.0	0.30	39.00	10.10
Shipyard	2.75	0.26	48162.42	440.00	1.00	0.30	85048.2	0.30	40.00	10.60
Shipyard	3.25	0.26	48585.82	439.00	1.10	0.30	77901.3	0.30	40.00	11.40
Shipyard	3.75	0.27	47103.90	424.00	1.00	0.30	70540.0	0.30	39.00	11.60
Shipyard	4.25	0.24	42816.92	385.00	1.00	0.30	66895.1	0.30	38.00	10.70
Shipyard	4.75	0.25	43081.55	398.00	0.90	0.30	69968.2	0.20	38.00	10.90
Shipyard	5.25	0.23	39641.37	373.00	1.00	0.30	75042.5	0.20	37.00	10.20
Shipyard	5.75	0.23	41335.00	385.00	0.90	0.30	69182.1	0.30	36.00	10.60
Shipyard	6.25	0.26	47156.83	420.00	1.10	0.30	53458.9	0.30	40.00	11.30
Shipyard	6.75	0.26	50385.30	442.00	1.20	0.30	45097.0	0.30	41.00	11.40
Shipyard	7.25	0.27	55042.76	469.00	1.30	0.30	34876.9	0.30	45.00	12.00
Shipyard	7.75	0.26	50861.63	438.00	1.20	0.30	31303.5	0.30	41.00	11.50
Shipyard	8.25	0.32	57689.05	481.00	1.40	0.30	53315.9	0.30	46.00	11.50
Shipyard	8.75	0.30	59806.08	507.00	1.30	0.30	67395.3	0.30	46.00	11.70
Shipyard	9.25	0.35	66157.17	553.00	1.40	0.30	68538.8	0.30	50.00	11.80
Shipyard	9.75	0.38	68803.45	585.00	1.40	0.30	57747.0	0.40	53.00	12.50
Shipyard	10.25	0.40	72508.26	616.00	1.50	0.40	48741.9	0.40	56.00	13.40
Shipyard	10.75	0.40	73566.77	618.00	1.70	0.40	45382.9	0.40	57.00	14.00
Shipyard	11.25	0.40	71979.00	613.00	1.50	0.30	50957.5	0.40	57.00	14.60
Shipyard	11.75	0.40	70920.48	600.00	1.70	0.30	59605.2	0.40	56.00	14.00
Shipyard	12.25	0.36	73037.51	604.00	1.50	0.30	59962.6	0.40	57.00	14.40
Shipyard	12.75	0.37	73566.77	601.00	1.60	0.40	43024.4	0.40	58.00	14.00
Shipyard	13.25	0.39	74096.03	604.00	1.70	0.40	36520.7	0.40	59.00	14.80
Shipyard	13.75	0.38	68803.45	595.00	1.60	0.40	51672.1	0.40	58.00	15.80

Shipyard	14.25	0.41	71979.00	653.00	1.80	0.40	42238.2	0.40	60.00	15.80
Shipyard	14.75	0.44	76213.06	693.00	1.60	0.40	27872.9	0.40	60.00	15.00
Shipyard	15.25	0.45	77800.83	692.00	1.60	0.40	25657.4	0.40	63.00	16.00
Shipyard	15.75	0.44	75683.80	660.00	1.70	0.40	24585.4	0.40	62.00	16.40
Shipyard	16.25	0.45	77271.57	662.00	1.80	0.40	27658.5	0.40	63.00	15.60
Shipyard	16.75	0.41	77271.57	657.00	1.80	0.40	23870.7	0.40	62.00	15.40
Shipyard	17.25	0.36	77271.57	650.00	1.60	0.40	22941.6	0.40	61.00	15.00
Shipyard	17.75	0.36	77271.57	657.00	1.50	0.30	22441.3	0.40	61.00	12.80
Shipyard	18.25	0.39	77800.83	655.00	1.70	0.30	20583.1	0.40	61.00	12.60
Shipyard	18.75	0.38	76742.31	644.00	1.60	0.30	20511.6	0.40	61.00	13.20
Shipyard	19.25	0.37	73037.51	621.00	1.40	0.30	22941.6	0.40	59.00	13.20
Shipyard	19.75	0.37	73037.51	633.00	1.50	0.30	24299.5	0.40	60.00	13.50
Shipyard	20.5	0.43	79917.86	643.00	1.90	0.40	26515.0	0.50	61.00	17.10
Shipyard	21.5	0.44	81505.63	656.00	1.90	0.40	21297.8	0.50	62.00	16.40
Shipyard	22.5	0.44	83622.66	644.00	2.10	0.40	19225.2	0.50	63.00	14.90
Shipyard	23.5	0.41	76213.06	645.00	2.00	0.40	27015.3	0.50	59.00	17.80
Shipyard	24.5	0.38	66686.42	580.00	1.80	0.40	23298.9	0.50	55.00	27.10
Shipyard	25.5	0.38	74625.28	601.00	2.10	0.40	30731.7	0.40	55.00	19.10
Shipyard	26.5	0.26	53984.25	498.00	1.30	0.30	75042.5	0.30	41.00	12.20
Shipyard	27.5	0.36	72508.26	621.00	1.50	0.30	54030.6	0.40	54.00	16.10
Shipyard	28.5	0.40	74096.03	626.00	1.90	0.40	40523.0	0.80	56.00	15.20
Shipyard	29.5	0.41	74625.28	636.00	1.80	0.40	38664.8	0.50	58.00	15.10
Shipyard	30.5	0.40	72508.26	614.00	1.90	0.40	30660.2	0.50	58.00	16.90
Shipyard	31.5	0.41	75154.54	621.00	1.70	0.40	22727.2	0.50	60.00	16.00
Shipyard	32.5	0.37	72508.26	571.00	1.90	0.40	14722.6	0.40	57.00	17.70
Shipyard	33.5	0.35	70391.23	563.00	2.00	0.40	13007.4	0.40	55.00	16.70
Shipyard	34.5	0.36	69332.71	560.00	1.80	0.40	12221.2	0.50	55.00	16.50
Shipyard	35.5	0.36	72508.26	577.00	1.90	0.30	12078.3	0.40	56.00	15.90
Shipyard	36.5	0.41	74625.28	593.00	1.90	0.40	12507.1	0.40	57.00	15.70
Shipyard	37.5	0.46	76742.31	602.00	1.80	0.40	12721.5	0.40	60.00	16.00
Shipyard	38.5	0.41	79388.60	614.00	2.00	0.40	14508.2	0.50	62.00	16.00
Shipyard	39.5	0.39	79917.86	586.00	2.20	0.40	12221.2	0.40	61.00	15.80

Table B.8 Total digestion metal concentrations Cr-Ho for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Cr ICP Total mg/kg	Cs ICP MS Total mg/kg	Cu ICP MS Total mg/kg	Dy ICP MS Total mg/kg	Er ICP MS Total mg/kg	Eu ICP MS Total mg/kg	Fe Total mg/kg	Ga ICP MS Total mg/kg	Gd ICP MS Total mg/kg	Hf ICP MS Total mg/kg	Ho ICP MS Total mg/kg
NE20	0.25	16.00	0.50	9.70	0.91	0.39	0.22	28606.18	2.70	0.70	0.60	0.14
NE20	0.75	15.00	0.40	5.80	0.39	0.20	0.16	22311.42	1.40	0.40	0.30	0.06
NE20	1.25	13.00	0.30	5.00	0.31	0.15	0.13	20353.05	1.10	0.30	0.20	0.05
NE20	1.75	13.00	0.30	5.40	0.25	0.13	0.12	18184.86	0.90	0.30	0.20	0.05
NE20	2.25	13.00	0.30	5.50	0.22	0.12	0.11	14408.00	0.80	0.20	0.20	0.04
NE20	2.75	11.00	0.30	5.60	0.22	0.12	0.10	13218.99	0.80	0.20	0.20	0.04
NE20	3.25	13.00	0.30	5.60	0.21	0.10	0.10	11190.68	0.70	0.20	0.20	0.04
NE20	3.75	13.00	0.30	5.00	0.18	0.10	0.10	8742.72	0.60	0.20	0.20	0.03
NE20	4.25	16.00	0.30	4.40	0.17	0.09	0.10	7693.59	0.60	0.20	0.10	0.03
NE20	4.75	16.00	0.20	4.00	0.17	0.09	0.10	7064.12	0.60	0.20	0.10	0.03
NE20	5.25	16.00	0.20	3.30	0.14	0.08	0.10	6154.88	0.60	0.20	0.10	0.02
NE20	5.75	17.00	0.20	4.00	0.13	0.08	0.09	6294.76	0.60	0.20	0.10	0.03
NE20	6.25	15.00	0.30	4.00	0.20	0.12	0.10	7064.12	0.80	0.20	0.20	0.04
NE20	6.75	18.00	0.30	4.90	0.20	0.12	0.10	8462.95	0.90	0.20	0.20	0.04
NE20	7.25	9.00	0.40	5.00	0.22	0.12	0.10	8742.72	0.90	0.20	0.20	0.04
NE20	7.75	11.00	0.40	5.40	0.24	0.12	0.10	7693.59	0.90	0.20	0.20	0.04
NE20	8.25	10.00	0.40	6.10	0.27	0.19	0.11	6364.70	0.90	0.30	0.20	0.04
NE20	8.75	10.00	0.40	7.20	0.27	0.15	0.12	6434.64	0.90	0.30	0.20	0.05
NE20	9.25	8.00	0.40	7.40	0.28	0.14	0.10	6434.64	0.90	0.30	0.20	0.05
NE20	9.75	8.00	0.40	6.70	0.30	0.15	0.10	6084.93	1.00	0.30	0.30	0.05
NE20	10.25	8.00	0.40	5.60	0.26	0.16	0.11	5945.05	0.90	0.30	0.20	0.05
NE20	10.75	9.00	0.40	6.00	0.27	0.14	0.11	5945.05	0.90	0.30	0.20	0.05
NE20	11.25	8.00	0.40	5.80	0.27	0.14	0.11	5805.17	0.90	0.30	0.20	0.05
NE20	11.75	7.00	0.40	5.90	0.24	0.14	0.11	5875.11	0.90	0.30	0.20	0.05
NE20	12.25	8.00	0.40	5.60	0.26	0.13	0.10	5525.40	0.90	0.30	0.20	0.04

NE20	12.75	8.00	0.40	5.90	0.26	0.15	0.11	5525.40	0.90	0.30	0.20	0.05
NE20	13.25	8.00	0.40	5.60	0.25	0.14	0.10	5315.57	0.90	0.20	0.20	0.05
NE20	13.75	8.00	0.40	5.30	0.27	0.14	0.10	5525.40	0.90	0.30	0.20	0.04
NE20	14.25	8.00	0.40	5.10	0.29	0.14	0.11	5455.46	0.90	0.30	0.20	0.05
NE20	14.75	9.00	0.40	5.40	0.28	0.16	0.11	5665.28	1.00	0.30	0.30	0.05
NE20	15.25	9.00	0.40	5.50	0.27	0.15	0.11	5945.05	1.00	0.30	0.20	0.05
NE20	15.75	9.00	0.40	5.60	0.29	0.15	0.12	6154.88	1.00	0.30	0.20	0.05
NE20	16.25	10.00	0.40	5.80	0.30	0.16	0.12	6084.93	1.00	0.30	0.20	0.05
NE20	16.75	9.00	0.40	5.90	0.28	0.15	0.11	6154.88	1.00	0.30	0.20	0.05
NE20	17.25	9.00	0.40	6.70	0.28	0.15	0.11	6294.76	1.00	0.30	0.20	0.05
NE20	17.75	9.00	0.40	6.00	0.28	0.14	0.11	6504.58	1.00	0.30	0.20	0.05
NE20	18.25	10.00	0.40	5.70	0.28	0.16	0.12	6504.58	1.00	0.30	0.20	0.05
NE20	18.75	10.00	0.40	6.60	0.32	0.16	0.12	6364.70	1.00	0.30	0.30	0.05
NE20	19.25	10.00	0.40	6.00	0.30	0.15	0.11	5945.05	1.00	0.30	0.20	0.05
NE20	19.75	10.00	0.40	5.90	0.27	0.16	0.12	5805.17	1.00	0.30	0.20	0.05
NE20	20.5	11.00	0.40	5.80	0.30	0.17	0.12	5665.28	1.00	0.30	0.20	0.05
NE20	21.5	10.00	0.40	5.30	0.28	0.14	0.12	5105.75	0.90	0.30	0.20	0.05
NE20	22.5	11.00	0.40	5.60	0.26	0.16	0.12	5245.63	1.00	0.30	0.20	0.05
NE20	23.5	12.00	0.40	5.40	0.26	0.14	0.11	5105.75	0.90	0.30	0.20	0.05
NE20	24.5	12.00	0.40	5.80	0.28	0.14	0.12	5035.81	1.00	0.30	0.20	0.05
NE20	25.5	12.00	0.40	5.70	0.29	0.14	0.12	4476.27	1.00	0.30	0.20	0.05
NE20	26.5	13.00	0.40	5.80	0.28	0.16	0.13	4056.62	1.10	0.30	0.20	0.05
NE20	27.5	14.00	0.40	5.20	0.25	0.15	0.12	3846.80	1.10	0.30	0.20	0.05
NE20	28.5	14.00	0.40	5.20	0.24	0.12	0.11	3427.15	0.90	0.20	0.20	0.04
NE20	29.5	14.00	0.30	5.10	0.23	0.11	0.11	3567.03	0.90	0.20	0.20	0.04
NE20	30.5	12.00	0.30	5.40	0.18	0.10	0.11	3427.15	0.80	0.20	0.20	0.03
NE20	31.5	14.00	0.30	5.30	0.18	0.09	0.10	3427.15	0.80	0.20	0.10	0.03
NE20	32.5	14.00	0.30	5.00	0.19	0.11	0.10	3497.09	0.70	0.20	0.10	0.03
NE20	33.5	15.00	0.30	5.20	0.19	0.10	0.10	3217.32	0.60	0.20	0.10	0.03
NE20	34.5	15.00	0.30	4.40	0.17	0.09	0.11	2937.55	0.60	0.20	0.10	0.03
NE20	35.5	14.00	0.40	5.00	0.22	0.12	0.11	3636.97	0.90	0.20	0.20	0.04
NE20	36.5	14.00	0.50	6.10	0.41	0.16	0.13	4406.33	1.00	0.30	0.30	0.05

NE20	37.5	13.00	0.30	5.30	0.22	0.12	0.11	3427.15	0.70	0.20	0.20	0.04
NE20	38.5	14.00	0.30	4.20	0.19	0.09	0.10	3287.26	0.60	0.20	0.10	0.03
NE20	39.5	16.00	0.30	3.80	0.16	0.10	0.10	2937.55	0.60	0.20	0.10	0.03
NE20	40.5	16.00	0.20	3.80	0.14	0.08	0.10	3357.20	0.60	0.20	0.10	0.02
NE20	41.5	16.00	0.20	3.80	0.12	0.06	0.09	3706.91	0.50	0.10	<0.1	0.02
NE20	42.5	19.00	0.10	2.60	0.09	0.04	0.10	2378.02	0.30	0.10	<0.1	<0.02
NE20	43.5	20.00	<0.1	2.10	0.07	0.04	0.09	2238.14	0.30	<0.1	<0.1	<0.02
Isadore's	0.25	64.00	4.70	25.70	3.41	1.98	1.14	33292.28	15.00	3.70	2.90	0.65
Isadore's	0.75	77.00	5.10	26.80	3.54	2.11	1.18	36439.66	15.70	3.90	3.20	0.69
Isadore's	1.25	66.00	5.00	26.70	3.60	2.13	1.17	37908.44	15.30	3.80	3.20	0.69
Isadore's	1.75	69.00	5.10	27.40	3.66	2.14	1.21	37488.78	15.90	3.90	3.20	0.69
Isadore's	2.25	68.00	4.60	25.80	3.35	2.06	1.14	37558.73	14.40	3.50	2.70	0.66
Isadore's	2.75	71.00	4.60	25.80	3.32	1.96	1.14	38537.91	14.30	3.60	2.80	0.61
Isadore's	3.25	79.00	4.70	25.40	3.38	1.95	1.10	37908.44	14.20	3.40	2.80	0.63
Isadore's	3.75	69.00	5.20	27.60	3.72	2.26	1.24	38258.14	16.20	4.00	3.20	0.72
Isadore's	4.25	71.00	5.20	27.80	3.81	2.21	1.19	40706.11	16.00	3.90	3.20	0.70
Isadore's	4.75	72.00	5.30	28.20	3.77	2.22	1.24	41195.70	16.20	4.10	3.30	0.73
Isadore's	5.25	72.00	5.30	28.40	3.88	2.25	1.24	40985.87	16.70	4.10	3.40	0.73
Isadore's	5.75	73.00	5.30	27.70	3.92	2.28	1.26	39097.45	16.60	4.20	3.60	0.74
Isadore's	6.25	69.00	5.10	26.90	3.79	2.25	1.22	35390.53	15.60	4.00	3.40	0.73
Isadore's	6.75	75.00	5.20	28.00	3.93	2.32	1.29	33711.93	16.30	4.30	3.50	0.75
Isadore's	7.25	72.00	5.00	27.80	3.82	2.32	1.27	32033.33	16.00	4.20	3.50	0.73
Isadore's	7.75	71.00	5.20	28.20	3.93	2.27	1.29	32173.21	16.20	4.20	3.60	0.78
Isadore's	8.25	73.00	5.10	28.50	3.99	2.32	1.32	31683.62	16.40	4.20	3.60	0.75
Isadore's	8.75	74.00	5.20	29.30	3.95	2.32	1.30	32243.15	16.50	4.20	3.50	0.76
Isadore's	9.25	73.00	5.10	28.60	3.84	2.28	1.26	32033.33	16.10	4.20	3.40	0.74
Isadore's	9.75	72.00	5.20	28.20	3.79	2.27	1.32	32033.33	16.40	4.10	3.40	0.73
Isadore's	10.25	73.00	5.10	28.80	3.93	2.35	1.28	30914.26	16.20	4.30	3.50	0.76
Isadore's	10.75	71.00	5.00	27.50	3.83	2.19	1.26	31124.08	16.10	4.20	3.30	0.72
Isadore's	11.25	63.00	4.60	24.90	3.40	1.96	1.12	35740.24	14.10	3.70	3.00	0.65
Isadore's	11.75	41.00	3.10	15.40	2.11	1.32	0.73	36789.37	9.00	2.30	1.80	0.40
Isadore's	12.25	37.00	2.60	13.30	1.79	1.04	0.65	36789.37	7.80	2.00	1.60	0.34

Isadore's	12.75	38.00	3.00	14.60	1.88	1.12	0.67	55533.76	8.70	2.10	1.60	0.36
Isadore's	13.25	44.00	3.20	16.20	2.10	1.26	0.74	67983.39	9.60	2.30	1.80	0.40
Isadore's	13.75	45.00	3.50	17.50	2.30	1.38	0.78	75537.10	10.10	2.50	2.00	0.44
Isadore's	14.25	54.00	4.00	19.90	2.61	1.58	0.88	78334.77	11.80	2.80	2.10	0.51
Isadore's	14.75	71.00	5.50	26.90	3.51	2.06	1.12	55883.47	16.00	3.70	2.90	0.67
Isadore's	15.25	78.00	5.70	30.60	3.77	2.16	1.24	52036.67	17.20	4.00	3.20	0.71
Isadore's	15.75	73.00	5.50	28.20	3.75	2.26	1.18	45532.09	17.10	4.00	3.20	0.72
Isadore's	16.25	75.00	5.70	27.80	3.62	2.19	1.19	46231.50	16.90	4.10	3.10	0.70
Isadore's	16.75	71.00	5.20	27.10	3.50	2.04	1.15	45182.38	16.10	3.90	2.90	0.68
Isadore's	17.25	73.00	5.50	28.60	3.67	2.20	1.22	44413.02	16.50	4.10	3.10	0.70
Isadore's	17.75	78.00	5.90	30.70	3.91	2.32	1.28	42664.47	17.80	4.50	3.20	0.74
Isadore's	18.25	71.00	5.30	28.90	3.96	2.28	1.30	38467.97	16.60	4.20	3.50	0.74
Isadore's	18.75	70.00	5.20	29.00	4.03	2.34	1.26	37278.96	16.50	4.20	3.40	0.77
Isadore's	19.25	68.00	5.40	29.10	3.83	2.23	1.23	42174.88	16.60	4.10	3.10	0.72
Isadore's	19.75	73.00	5.40	28.50	3.56	2.08	1.20	44552.90	16.60	3.90	3.00	0.67
Isadore's	20.5	71.00	6.60	31.80	3.79	2.22	1.26	45182.38	18.80	4.60	3.30	0.73
Isadore's	21.5	73.00	6.90	34.10	3.93	2.32	1.33	43643.66	19.80	4.70	3.40	0.77
Isadore's	22.5	73.00	6.70	31.40	4.07	2.41	1.32	48469.64	19.10	4.80	3.40	0.81
Isadore's	23.5	69.00	6.40	29.80	3.79	2.25	1.27	56862.65	18.30	4.50	3.30	0.75
Isadore's	24.5	71.00	6.50	30.40	3.93	2.35	1.33	47700.28	18.60	4.80	3.40	0.76
Isadore's	25.5	71.00	6.60	31.00	4.03	2.42	1.34	41265.64	19.40	4.80	3.50	0.79
Isadore's	26.5	73.00	6.50	31.30	3.95	2.40	1.34	39796.86	19.00	4.90	3.50	0.82
Isadore's	27.5	70.00	6.40	29.60	3.81	2.28	1.31	46721.10	18.50	4.70	3.40	0.77
Isadore's	28.5	71.00	6.40	28.90	3.75	2.25	1.26	51337.25	18.80	4.60	3.40	0.75
Isadore's	29.5	67.00	6.10	27.20	3.61	2.18	1.22	52246.50	17.40	4.40	3.30	0.72
Isadore's	30.5	58.00	5.00	22.40	3.08	1.91	1.04	64486.30	14.60	3.60	2.80	0.60
Isadore's	31.5	65.00	5.70	26.90	3.63	2.17	1.21	53785.22	16.40	4.40	3.40	0.71
Isadore's	32.5	57.00	5.20	24.80	3.40	2.09	1.17	43293.95	14.90	4.20	3.30	0.68
Isadore's	33.5	39.00	3.70	17.10	2.37	1.39	0.85	39936.75	10.50	2.90	2.00	0.46
Isadore's	34.5	68.00	6.40	28.90	3.54	2.14	1.20	59590.38	17.70	4.40	3.20	0.70
Isadore's	35.5	75.00	7.40	31.00	3.97	2.33	1.28	56023.35	20.40	4.70	3.50	0.79
Isadore's	36.5	70.00	6.60	29.00	3.66	2.24	1.25	60429.68	18.10	4.50	3.30	0.73

Isadore's	37.5	70.00	6.60	30.20	3.72	2.24	1.27	51127.43	18.10	4.60	3.40	0.73
Isadore's	38.5	74.00	7.40	31.40	4.16	2.54	1.36	57072.48	19.40	5.00	3.50	0.81
Isadore's	39.5	81.00	7.80	38.20	4.53	2.73	1.47	47490.46	21.00	5.40	4.10	0.89
Shipyard	0.25	43.00	3.60	19.80	2.32	1.35	0.78	27277.29	10.40	2.60	2.00	0.45
Shipyard	0.75	46.00	3.60	18.80	2.31	1.32	0.77	28186.53	10.50	2.60	1.90	0.43
Shipyard	1.25	46.00	3.80	19.10	2.44	1.40	0.78	28676.12	10.80	2.70	2.00	0.45
Shipyard	1.75	47.00	3.70	18.70	2.37	1.39	0.79	28955.89	10.50	2.60	2.10	0.46
Shipyard	2.25	48.00	3.80	19.30	2.53	1.46	0.82	31613.68	10.90	2.80	2.20	0.46
Shipyard	2.75	50.00	3.90	21.10	2.55	1.50	0.81	31613.68	11.40	2.80	2.30	0.48
Shipyard	3.25	52.00	4.00	20.30	2.60	1.51	0.85	33921.75	11.70	2.80	2.30	0.49
Shipyard	3.75	50.00	3.90	19.90	2.59	1.54	0.83	35250.65	11.70	2.80	2.20	0.50
Shipyard	4.25	46.00	3.50	18.20	2.50	1.44	0.81	35740.24	10.40	2.70	2.20	0.47
Shipyard	4.75	47.00	3.60	18.90	2.62	1.48	0.81	37418.84	10.60	2.80	2.30	0.48
Shipyard	5.25	42.00	3.30	17.40	2.42	1.37	0.75	36229.83	9.60	2.60	2.00	0.45
Shipyard	5.75	44.00	3.50	18.80	2.40	1.39	0.78	36579.54	10.00	2.70	1.90	0.45
Shipyard	6.25	50.00	4.00	20.60	2.65	1.49	0.83	37139.08	11.40	2.90	2.20	0.49
Shipyard	6.75	54.00	4.20	23.60	2.68	1.58	0.87	36089.95	12.20	3.10	2.10	0.51
Shipyard	7.25	58.00	4.60	23.40	2.90	1.72	0.94	36719.43	13.40	3.20	2.30	0.56
Shipyard	7.75	54.00	4.40	22.00	2.77	1.62	0.88	33991.70	12.40	2.90	2.10	0.52
Shipyard	8.25	61.00	4.90	22.90	2.82	1.67	0.92	33991.70	14.00	3.20	2.30	0.53
Shipyard	8.75	63.00	4.90	22.70	2.87	1.68	0.94	32173.21	14.20	3.10	2.30	0.54
Shipyard	9.25	68.00	5.40	24.50	3.10	1.79	1.02	32522.92	15.50	3.50	2.40	0.58
Shipyard	9.75	70.00	5.80	26.90	3.29	1.93	1.09	32313.09	16.70	3.70	2.70	0.63
Shipyard	10.25	74.00	6.00	27.60	3.45	1.98	1.12	33292.28	17.40	3.90	2.80	0.65
Shipyard	10.75	77.00	6.10	29.00	3.58	2.11	1.17	33572.05	17.90	4.00	3.00	0.68
Shipyard	11.25	76.00	6.10	27.70	3.61	2.14	1.16	33292.28	17.60	4.00	2.90	0.68
Shipyard	11.75	73.00	5.80	27.50	3.59	2.07	1.13	33082.45	17.00	4.00	2.90	0.68
Shipyard	12.25	77.00	6.30	28.40	3.57	2.10	1.19	34900.94	17.60	4.20	2.80	0.68
Shipyard	12.75	77.00	6.30	29.00	3.60	2.13	1.17	36719.43	18.00	4.00	2.90	0.70
Shipyard	13.25	78.00	6.50	29.20	3.68	2.14	1.18	37978.38	18.20	4.10	3.00	0.70
Shipyard	13.75	72.00	6.10	28.20	3.90	2.22	1.19	37628.67	17.20	4.30	2.80	0.72
Shipyard	14.25	75.00	6.00	29.40	3.98	2.32	1.27	37628.67	17.40	4.40	3.00	0.77

Shipyard	14.75	81.00	6.30	31.90	3.99	2.27	1.30	34761.06	18.70	4.30	3.20	0.74
Shipyard	15.25	82.00	6.50	33.00	3.99	2.38	1.29	35110.76	19.30	4.60	3.30	0.77
Shipyard	15.75	79.00	6.40	31.90	4.24	2.44	1.33	33991.70	18.90	4.50	3.40	0.84
Shipyard	16.25	82.00	6.50	31.50	4.03	2.34	1.30	34271.46	19.10	4.40	3.40	0.75
Shipyard	16.75	81.00	6.40	30.80	3.93	2.30	1.31	34131.58	19.20	4.40	3.20	0.75
Shipyard	17.25	79.00	5.80	28.10	3.41	2.02	1.16	34341.41	17.30	3.80	2.80	0.65
Shipyard	17.75	79.00	5.70	27.30	3.27	1.89	1.11	33572.05	17.10	3.80	2.80	0.62
Shipyard	18.25	81.00	6.00	27.50	3.38	1.96	1.13	33152.40	17.70	3.80	2.90	0.63
Shipyard	18.75	80.00	5.90	27.10	3.37	1.95	1.13	33152.40	17.20	3.80	2.80	0.64
Shipyard	19.25	74.00	5.60	27.10	3.36	1.96	1.12	33502.10	16.60	3.80	2.80	0.65
Shipyard	19.75	79.00	5.70	26.60	3.37	2.06	1.12	34061.64	16.20	3.70	2.70	0.64
Shipyard	20.5	77.00	7.20	31.80	4.00	2.42	1.36	36299.77	19.80	4.80	3.40	0.79
Shipyard	21.5	79.00	7.40	32.30	3.99	2.31	1.32	34970.88	20.70	4.80	3.50	0.75
Shipyard	22.5	78.00	7.50	32.30	3.94	2.39	1.32	34551.23	21.10	4.80	3.60	0.79
Shipyard	23.5	72.00	6.70	31.40	3.89	2.34	1.31	36159.89	19.20	4.80	3.30	0.79
Shipyard	24.5	64.00	6.00	31.00	4.06	2.37	1.28	38467.97	16.90	4.60	3.00	0.80
Shipyard	25.5	70.00	6.90	31.40	3.76	2.25	1.25	39027.50	19.30	4.50	3.10	0.74
Shipyard	26.5	49.00	4.80	22.10	2.69	1.59	0.90	31893.44	13.30	3.30	2.10	0.53
Shipyard	27.5	68.00	6.40	30.20	3.53	2.07	1.20	37978.38	17.90	4.20	2.90	0.68
Shipyard	28.5	70.00	6.60	31.40	3.70	2.23	1.22	36579.54	18.70	4.50	3.20	0.75
Shipyard	29.5	69.00	6.50	31.80	3.85	2.25	1.28	35950.07	18.60	4.60	3.20	0.74
Shipyard	30.5	70.00	6.40	30.50	3.80	2.22	1.23	37348.90	18.20	4.50	3.20	0.74
Shipyard	31.5	71.00	6.70	31.40	3.99	2.30	1.30	37348.90	18.90	4.60	3.40	0.77
Shipyard	32.5	68.00	6.70	31.10	3.91	2.34	1.29	35530.42	18.60	4.60	3.30	0.76
Shipyard	33.5	68.00	6.60	30.50	3.65	2.15	1.20	35670.30	17.90	4.40	3.10	0.71
Shipyard	34.5	66.00	6.50	31.10	3.72	2.19	1.22	34271.46	18.20	4.30	3.20	0.77
Shipyard	35.5	69.00	6.60	30.80	3.79	2.20	1.22	33921.75	18.40	4.40	3.20	0.72
Shipyard	36.5	71.00	6.70	31.10	3.84	2.25	1.27	34900.94	18.70	4.50	3.20	0.74
Shipyard	37.5	73.00	6.90	32.00	4.05	2.33	1.29	34900.94	18.90	4.90	3.60	0.79
Shipyard	38.5	75.00	7.10	31.40	4.05	2.41	1.32	33781.87	19.60	4.80	3.70	0.82
Shipyard	39.5	75.00	7.10	30.80	4.16	2.42	1.29	33012.51	19.50	4.90	3.80	0.81

Table B.9 Total digestion metal concentrations K-P for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	K Total mg/kg	La ICP Total mg/kg	Li ICP Total mg/kg	Mg Total mg/kg	Mn Total mg/kg	Mo ICP MS Total mg/kg	Na Total mg/kg	Nb ICP MS Total mg/kg	Nd ICP MS Total mg/kg	Ni ICP MS Total mg/kg	P Total mg/kg
NE20	0.25	2183.3	3.00	17.00	3063.4	859.65	15.80	593.49	1.80	3.60	34.00	1418.37
NE20	0.75	1303.3	2.00	5.00	2508.6	851.90	4.29	445.11	1.10	2.60	39.50	1156.51
NE20	1.25	1021.1	2.00	4.00	2339.8	743.48	3.75	445.11	0.90	1.90	34.70	1029.95
NE20	1.75	921.5	1.00	3.00	2291.5	573.10	2.95	445.11	0.70	1.70	26.20	1003.77
NE20	2.25	846.8	<1	2.00	2122.7	433.70	2.18	593.49	0.60	1.40	18.70	947.03
NE20	2.75	772.0	3.00	2.00	2098.6	387.23	1.97	445.11	0.60	1.30	16.60	942.67
NE20	3.25	689.0	2.00	2.00	2285.5	371.74	1.90	445.11	0.50	1.30	16.90	907.75
NE20	3.75	655.8	2.00	2.00	2478.5	371.74	1.45	445.11	0.60	1.10	16.30	798.65
NE20	4.25	664.1	1.00	2.00	2840.3	425.95	1.14	370.93	0.40	1.20	16.60	741.92
NE20	4.75	614.3	2.00	2.00	2973.0	518.89	1.18	370.93	0.40	1.10	18.00	724.46
NE20	5.25	564.5	1.00	2.00	3033.3	526.63	1.03	370.93	0.40	1.00	17.20	663.36
NE20	5.75	680.7	2.00	2.00	3057.4	480.16	1.26	445.11	0.50	1.00	16.30	637.17
NE20	6.25	855.1	2.00	2.00	2792.1	371.74	1.78	445.11	0.60	1.30	15.10	632.81
NE20	6.75	929.8	2.00	2.00	2508.6	286.55	2.33	445.11	0.70	1.40	17.40	654.63
NE20	7.25	1021.1	3.00	2.00	2249.3	224.59	1.57	519.30	0.80	1.50	12.20	663.36
NE20	7.75	979.6	2.00	2.00	2170.9	193.61	1.65	519.30	0.70	1.60	13.00	741.92
NE20	8.25	1037.7	2.00	3.00	2285.5	185.87	1.45	593.49	0.80	1.80	12.90	781.19
NE20	8.75	1037.7	3.00	3.00	2303.6	178.13	1.59	519.30	0.80	1.90	12.80	798.65
NE20	9.25	979.6	1.00	2.00	2008.1	147.15	1.96	519.30	0.80	1.70	11.80	785.56
NE20	9.75	1029.4	3.00	3.00	1990.0	139.40	1.49	519.30	0.70	1.90	10.90	707.00
NE20	10.25	1004.5	2.00	2.00	1990.0	139.40	1.36	519.30	0.70	1.80	11.30	711.37
NE20	10.75	1004.5	1.00	2.00	2008.1	139.40	1.51	593.49	0.70	1.90	11.70	720.09
NE20	11.25	987.9	2.00	2.00	2032.2	139.40	1.64	593.49	0.70	1.80	10.60	724.46
NE20	11.75	946.4	1.00	2.00	1965.9	131.66	1.50	519.30	0.70	1.70	10.30	698.27
NE20	12.25	954.7	1.00	2.00	1947.8	123.91	1.34	519.30	0.70	1.70	10.50	680.82
NE20	12.75	987.9	1.00	2.00	2032.2	131.66	1.25	519.30	0.70	1.70	11.10	715.73

NE20	13.25	954.7	2.00	2.00	2032.2	123.91	1.17	519.30	0.60	1.60	11.10	689.54
NE20	13.75	1029.4	3.00	2.00	2146.8	131.66	1.26	593.49	0.80	1.80	11.20	659.00
NE20	14.25	1046.0	3.00	2.00	2110.6	131.66	1.32	519.30	0.70	1.90	11.50	632.81
NE20	14.75	1079.2	2.00	3.00	2183.0	131.66	2.01	593.49	0.80	1.90	12.30	659.00
NE20	15.25	1095.8	3.00	3.00	2207.1	123.91	1.47	519.30	0.80	2.00	12.20	663.36
NE20	15.75	1095.8	2.00	3.00	2243.3	131.66	1.28	593.49	0.80	2.00	12.60	676.45
NE20	16.25	1079.2	2.00	3.00	2213.1	123.91	1.09	593.49	0.80	1.90	12.00	667.72
NE20	16.75	1079.2	<1	3.00	2201.1	123.91	1.15	593.49	0.80	1.90	12.40	680.82
NE20	17.25	1079.2	3.00	3.00	2225.2	123.91	1.30	593.49	1.20	1.80	12.60	685.18
NE20	17.75	1037.7	2.00	3.00	2164.9	123.91	1.37	593.49	0.80	1.80	12.30	663.36
NE20	18.25	1079.2	2.00	3.00	2291.5	131.66	1.44	593.49	0.70	1.80	12.50	693.91
NE20	18.75	1137.3	3.00	3.00	2315.7	131.66	1.50	593.49	0.80	1.90	12.90	698.27
NE20	19.25	1104.1	2.00	3.00	2357.9	131.66	1.50	593.49	0.80	2.00	12.60	702.64
NE20	19.75	1104.1	2.00	3.00	2363.9	139.40	1.66	593.49	0.70	2.00	12.80	702.64
NE20	20.5	1137.3	2.00	3.00	2412.1	139.40	1.50	593.49	0.80	2.00	13.10	698.27
NE20	21.5	1095.8	2.00	3.00	2321.7	131.66	1.42	593.49	0.70	1.80	13.00	641.54
NE20	22.5	1120.7	3.00	3.00	2412.1	139.40	1.49	593.49	0.70	1.90	13.30	672.09
NE20	23.5	1104.1	3.00	3.00	2321.7	139.40	1.45	667.67	0.70	2.00	14.30	663.36
NE20	24.5	1145.6	3.00	3.00	2472.4	147.15	1.40	667.67	0.90	1.90	15.20	707.00
NE20	25.5	1145.6	2.00	3.00	2472.4	154.89	1.43	593.49	0.80	1.80	14.80	724.46
NE20	26.5	1212.0	2.00	3.00	2581.0	154.89	1.33	593.49	0.80	1.90	14.90	689.54
NE20	27.5	1178.8	2.00	3.00	2774.0	170.38	1.26	593.49	0.80	1.80	16.00	663.36
NE20	28.5	1012.8	2.00	3.00	2846.3	178.13	1.26	593.49	0.60	1.50	15.60	593.53
NE20	29.5	963.0	3.00	3.00	2647.3	170.38	1.45	593.49	0.70	1.50	15.50	632.81
NE20	30.5	788.6	1.00	2.00	2376.0	162.64	1.76	593.49	0.50	1.30	14.90	619.72
NE20	31.5	763.7	<1	2.00	2466.4	170.38	1.82	667.67	0.50	1.20	16.00	619.72
NE20	32.5	713.9	<1	2.00	2544.8	178.13	1.58	593.49	0.50	1.20	15.20	602.26
NE20	33.5	705.6	2.00	2.00	2767.9	201.36	1.56	519.30	0.50	1.20	16.00	610.99
NE20	34.5	697.3	1.00	2.00	2840.3	201.36	1.36	519.30	0.50	1.10	16.00	519.34
NE20	35.5	946.4	1.00	2.00	2828.2	170.38	1.52	519.30	0.70	1.50	15.60	549.89
NE20	36.5	1228.6	3.00	3.00	2786.0	162.64	1.91	593.49	0.80	2.00	15.20	580.44
NE20	37.5	871.7	1.00	2.00	2526.7	170.38	1.96	593.49	0.60	1.40	15.30	602.26

NE20	38.5	689.0	2.00	2.00	2544.8	178.13	1.76	519.30	0.50	1.30	15.40	545.53
NE20	39.5	730.5	1.00	2.00	2966.9	201.36	1.35	519.30	0.50	1.10	16.80	514.98
NE20	40.5	647.5	1.00	2.00	3015.2	193.61	1.36	519.30	0.40	1.00	16.90	453.88
NE20	41.5	531.3	<1	1.00	3153.9	201.36	1.59	445.11	0.30	0.80	18.10	418.96
NE20	42.5	348.7	1.00	1.00	3618.2	216.85	1.09	370.93	0.20	0.60	19.10	305.49
NE20	43.5	282.3	<1	1.00	3570.0	224.59	1.32	370.93	0.20	0.40	19.50	253.12
Isadore's	0.25	14859.6	26.00	43.00	11397.4	379.48	1.14	5118.82	10.80	23.60	33.30	1457.65
Isadore's	0.75	16104.9	28.00	46.00	12121.0	394.97	1.23	5415.56	11.80	25.50	39.80	1187.06
Isadore's	1.25	16187.9	27.00	46.00	11940.1	418.21	1.11	5341.37	11.80	24.80	34.10	1104.14
Isadore's	1.75	16603.0	29.00	48.00	12301.9	433.70	1.15	5489.75	12.20	25.50	34.80	995.04
Isadore's	2.25	16603.0	29.00	48.00	12422.5	449.19	1.08	5489.75	11.20	23.50	32.30	1056.14
Isadore's	2.75	16436.9	29.00	47.00	12241.6	456.93	1.11	5341.37	11.00	23.10	31.00	1069.23
Isadore's	3.25	16603.0	28.00	47.00	12121.0	456.93	1.06	5415.56	11.00	23.60	31.50	1029.95
Isadore's	3.75	16603.0	29.00	47.00	12241.6	449.19	1.13	5563.93	12.30	25.60	35.90	977.58
Isadore's	4.25	17267.1	30.00	49.00	12543.1	464.67	1.20	5712.30	12.20	26.00	35.60	981.95
Isadore's	4.75	17350.1	29.00	49.00	12603.5	433.70	1.41	5860.67	12.60	26.10	37.60	877.21
Isadore's	5.25	17516.1	30.00	49.00	12543.1	402.72	1.23	6009.05	12.90	27.00	38.70	833.56
Isadore's	5.75	18014.2	31.00	50.00	12784.4	371.74	1.24	6379.97	13.00	26.90	37.80	803.01
Isadore's	6.25	17516.1	30.00	48.00	12422.5	348.51	1.14	6305.79	12.80	26.30	36.20	759.37
Isadore's	6.75	17765.2	30.00	48.00	12724.1	356.25	1.21	6528.35	13.00	27.60	39.50	789.92
Isadore's	7.25	17848.2	31.00	48.00	12784.4	364.00	1.24	6676.72	13.20	27.00	38.70	798.65
Isadore's	7.75	17931.2	31.00	49.00	12784.4	379.48	1.22	6750.90	13.10	27.30	39.20	842.29
Isadore's	8.25	17599.1	30.00	48.00	12663.8	379.48	1.28	6602.53	13.20	27.20	39.60	837.93
Isadore's	8.75	17682.1	31.00	48.00	12603.5	387.23	1.39	6528.35	13.20	26.90	40.90	881.57
Isadore's	9.25	17682.1	30.00	48.00	12543.1	379.48	1.34	6602.53	12.80	26.40	39.30	855.38
Isadore's	9.75	17848.2	31.00	48.00	12784.4	387.23	1.51	6602.53	13.00	26.70	39.80	903.39
Isadore's	10.25	17433.1	30.00	46.00	12663.8	379.48	1.52	6528.35	13.10	27.50	39.80	833.56
Isadore's	10.75	17516.1	30.00	47.00	12784.4	379.48	1.54	6379.97	12.80	26.80	38.80	803.01
Isadore's	11.25	15689.8	26.00	43.00	12000.4	387.23	1.94	5489.75	11.40	23.20	37.80	833.56
Isadore's	11.75	10874.9	18.00	30.00	9708.9	433.70	1.29	3486.73	6.90	14.50	30.20	872.84
Isadore's	12.25	8882.6	15.00	26.00	8804.3	433.70	1.16	2744.87	6.00	12.80	27.40	881.57
Isadore's	12.75	9712.7	16.00	28.00	9166.1	464.67	1.39	2744.87	6.40	13.40	30.20	837.93

Isadore's	13.25	10376.8	16.00	31.00	9286.8	449.19	1.63	2967.43	7.10	14.90	34.60	789.92
Isadore's	13.75	11041.0	18.00	32.00	9347.1	456.93	1.99	3189.99	7.70	15.70	36.60	772.46
Isadore's	14.25	13033.3	22.00	39.00	10432.5	557.61	2.26	3560.92	8.70	18.70	39.30	820.47
Isadore's	14.75	16603.0	28.00	51.00	12121.0	526.63	1.92	4376.96	11.90	24.60	42.80	981.95
Isadore's	15.25	18097.2	31.00	55.00	13025.6	441.44	1.40	5267.19	13.20	26.10	42.00	885.93
Isadore's	15.75	17516.1	31.00	54.00	12844.7	464.67	1.44	4673.70	13.00	25.90	39.80	1091.05
Isadore's	16.25	17765.2	31.00	54.00	12844.7	557.61	1.63	4673.70	12.80	25.90	39.10	1536.20
Isadore's	16.75	16935.0	30.00	51.00	12482.8	573.10	1.55	4525.33	12.30	24.70	37.50	1448.92
Isadore's	17.25	17765.2	32.00	53.00	12784.4	557.61	1.61	4822.07	12.90	25.90	39.40	1409.64
Isadore's	17.75	18595.3	33.00	56.00	13266.8	441.44	1.72	5044.63	14.00	28.10	41.50	990.67
Isadore's	18.25	17931.2	32.00	51.00	13206.5	418.21	1.52	5860.67	13.50	27.00	40.20	868.48
Isadore's	18.75	17516.1	31.00	50.00	12905.0	402.72	1.87	5712.30	13.50	27.00	40.90	859.75
Isadore's	19.25	16686.0	30.00	50.00	12241.6	394.97	2.64	4747.89	13.00	26.20	40.50	881.57
Isadore's	19.75	17018.0	29.00	50.00	12482.8	480.16	2.10	4451.14	12.40	25.00	40.00	960.13
Isadore's	20.5	19342.4	30.00	54.00	13990.4	604.08	1.76	4673.70	13.30	28.00	42.80	1047.41
Isadore's	21.5	20089.6	32.00	55.00	14653.8	542.12	1.71	5193.00	14.40	30.00	45.40	981.95
Isadore's	22.5	19757.5	32.00	55.00	14412.6	588.59	2.14	5341.37	14.40	29.10	43.90	1352.90
Isadore's	23.5	18678.3	30.00	52.00	13146.2	650.54	2.16	4747.89	13.40	28.70	41.00	2374.13
Isadore's	24.5	19508.5	31.00	54.00	14533.2	542.12	2.12	5341.37	14.20	29.50	43.20	1531.84
Isadore's	25.5	19757.5	31.00	53.00	14111.0	464.67	2.02	5489.75	14.80	30.10	44.80	1008.13
Isadore's	26.5	20089.6	32.00	54.00	14593.5	464.67	2.49	5489.75	14.50	30.50	45.10	933.94
Isadore's	27.5	18927.4	30.00	53.00	13749.2	480.16	2.11	5044.63	13.80	28.80	42.40	1195.79
Isadore's	28.5	18595.3	30.00	54.00	12482.8	449.19	1.72	4896.26	13.50	27.50	39.60	1165.24
Isadore's	29.5	17848.2	29.00	52.00	12663.8	449.19	1.86	4822.07	12.80	27.40	38.40	1204.52
Isadore's	30.5	14776.6	25.00	45.00	10673.7	518.89	1.93	3931.84	10.80	23.00	33.10	1230.71
Isadore's	31.5	17433.1	29.00	50.00	12121.0	495.65	1.72	5341.37	13.10	26.90	38.00	1187.06
Isadore's	32.5	16519.9	28.00	45.00	11819.5	464.67	1.54	5638.12	12.70	26.40	35.00	955.76
Isadore's	33.5	11456.0	19.00	35.00	10975.3	619.57	1.84	3115.80	7.80	17.10	30.30	1156.51
Isadore's	34.5	17599.1	31.00	55.00	11819.5	518.89	1.73	4154.40	13.30	27.40	37.50	1523.11
Isadore's	35.5	19259.4	32.00	66.00	12422.5	456.93	1.74	4080.22	14.20	29.60	41.80	1256.89
Isadore's	36.5	18014.2	30.00	56.00	11518.0	495.65	1.61	4154.40	13.30	27.90	37.80	1728.23
Isadore's	37.5	18097.2	31.00	54.00	11940.1	480.16	1.98	4376.96	13.60	28.20	39.60	1269.98

Isadore's	38.5	18595.3	33.00	58.00	11578.3	557.61	2.43	4154.40	14.80	30.80	41.20	1527.47
Isadore's	39.5	20255.6	36.00	60.00	11879.8	480.16	2.28	4822.07	17.00	34.00	46.30	1043.05
Shipyard	0.25	10376.8	19.00	33.00	8804.3	387.23	2.00	3709.29	7.40	16.80	34.20	1169.61
Shipyard	0.75	11539.1	19.00	35.00	9528.0	371.74	2.12	3783.47	7.50	16.30	33.60	1187.06
Shipyard	1.25	11373.0	20.00	35.00	9407.4	364.00	2.12	3560.92	7.90	17.70	35.20	1147.79
Shipyard	1.75	11207.0	20.00	35.00	9226.4	340.76	2.21	3412.54	7.70	17.30	34.10	1008.13
Shipyard	2.25	11622.1	21.00	37.00	9648.6	348.51	2.38	3560.92	7.90	18.00	34.80	1034.32
Shipyard	2.75	11871.1	22.00	37.00	9407.4	340.76	2.54	3635.10	8.30	18.40	35.90	1047.41
Shipyard	3.25	11871.1	21.00	38.00	9347.1	340.76	2.71	3560.92	8.30	18.20	36.60	986.31
Shipyard	3.75	11539.1	21.00	37.00	9045.5	348.51	3.11	3635.10	8.30	18.30	37.30	990.67
Shipyard	4.25	10542.9	20.00	35.00	8442.5	410.46	3.35	3486.73	8.00	17.60	36.30	951.40
Shipyard	4.75	10542.9	20.00	35.00	8623.4	441.44	3.32	3560.92	8.00	18.20	37.50	999.40
Shipyard	5.25	9795.7	19.00	32.00	8141.0	425.95	3.37	3560.92	7.20	17.00	35.50	1056.14
Shipyard	5.75	10127.8	19.00	33.00	8382.2	402.72	3.30	3709.29	7.30	16.90	37.00	1060.50
Shipyard	6.25	11456.0	21.00	37.00	8924.9	364.00	3.20	3857.66	8.10	18.50	38.80	1016.86
Shipyard	6.75	12203.2	22.00	39.00	9286.8	348.51	2.79	3857.66	8.50	18.80	41.10	1008.13
Shipyard	7.25	13199.3	24.00	42.00	9708.9	340.76	2.68	4006.03	9.20	20.80	43.70	999.40
Shipyard	7.75	12203.2	21.00	40.00	9045.5	309.78	2.73	3709.29	8.70	19.30	43.80	942.67
Shipyard	8.25	14029.5	25.00	46.00	10251.6	348.51	2.76	3783.47	9.80	20.80	47.70	916.48
Shipyard	8.75	14610.6	25.00	47.00	10613.4	356.25	2.49	3635.10	9.70	21.00	47.80	868.48
Shipyard	9.25	16187.9	27.00	51.00	11578.3	371.74	2.47	3857.66	10.80	22.50	50.90	811.74
Shipyard	9.75	17101.0	28.00	52.00	12060.7	364.00	2.46	4006.03	11.70	24.60	54.40	785.56
Shipyard	10.25	18097.2	30.00	55.00	12482.8	371.74	2.37	4302.77	12.30	25.60	54.60	807.38
Shipyard	10.75	18346.3	32.00	57.00	12482.8	371.74	2.46	4525.33	12.80	26.20	57.70	781.19
Shipyard	11.25	17848.2	31.00	56.00	12181.3	387.23	2.39	4376.96	12.60	26.50	59.20	785.56
Shipyard	11.75	17516.1	31.00	56.00	11940.1	394.97	2.26	4154.40	12.20	25.40	59.60	803.01
Shipyard	12.25	17682.1	32.00	58.00	11879.8	410.46	2.43	3931.84	12.40	26.20	59.60	776.83
Shipyard	12.75	17765.2	31.00	59.00	11578.3	418.21	2.24	3783.47	12.50	26.10	56.10	789.92
Shipyard	13.25	17765.2	32.00	60.00	11397.4	433.70	2.51	3709.29	12.70	26.60	56.70	763.74
Shipyard	13.75	16603.0	31.00	55.00	11035.6	480.16	2.58	3635.10	12.10	27.10	52.80	785.56
Shipyard	14.25	17848.2	33.00	55.00	12362.2	449.19	2.39	4747.89	13.10	28.10	47.20	781.19
Shipyard	14.75	19093.4	33.00	57.00	13146.2	387.23	1.84	5267.19	14.40	28.30	45.60	720.09

Shipyard	15.25	19425.5	34.00	60.00	13146.2	387.23	2.01	5118.82	14.70	29.20	46.20	733.19
Shipyard	15.75	19093.4	34.00	59.00	12965.3	387.23	2.01	4896.26	14.20	29.30	44.40	746.28
Shipyard	16.25	19425.5	34.00	61.00	13206.5	394.97	1.94	4747.89	14.50	28.80	44.20	755.01
Shipyard	16.75	19176.4	34.00	60.00	12482.8	402.72	2.02	4673.70	14.10	28.80	42.60	755.01
Shipyard	17.25	18927.4	33.00	59.00	12121.0	402.72	1.77	4451.14	12.50	25.30	40.80	763.74
Shipyard	17.75	19093.4	33.00	59.00	12241.6	402.72	1.60	4673.70	12.40	24.40	36.80	755.01
Shipyard	18.25	19093.4	33.00	60.00	12060.7	387.23	1.53	4525.33	13.10	25.30	37.80	741.92
Shipyard	18.75	18844.4	32.00	59.00	11819.5	387.23	1.55	4525.33	12.60	25.30	37.70	733.19
Shipyard	19.25	18014.2	32.00	57.00	11518.0	410.46	1.68	4302.77	12.00	24.70	37.40	750.64
Shipyard	19.75	18014.2	32.00	57.00	11518.0	425.95	1.57	4302.77	12.00	24.80	37.00	772.46
Shipyard	20.5	19425.5	33.00	59.00	12121.0	449.19	2.27	4673.70	14.20	30.60	45.60	899.03
Shipyard	21.5	19674.5	33.00	60.00	12121.0	410.46	2.28	4599.52	14.40	30.50	43.60	864.11
Shipyard	22.5	20006.6	33.00	60.00	11759.2	379.48	2.04	4673.70	14.90	31.30	43.80	837.93
Shipyard	23.5	18678.3	32.00	55.00	12000.4	464.67	2.09	4822.07	13.70	29.60	44.30	859.75
Shipyard	24.5	16187.9	29.00	48.00	10251.6	480.16	2.58	4080.22	12.10	28.00	49.50	951.40
Shipyard	25.5	17848.2	30.00	55.00	11156.2	542.12	2.31	3857.66	13.00	28.80	45.90	916.48
Shipyard	26.5	12867.3	22.00	41.00	9045.5	573.10	1.83	2819.06	8.90	20.70	33.50	833.56
Shipyard	27.5	17931.2	30.00	53.00	12060.7	557.61	2.18	4154.40	12.50	26.60	43.00	933.94
Shipyard	28.5	18761.3	30.00	53.00	12603.5	518.89	2.21	4599.52	13.70	28.50	44.70	859.75
Shipyard	29.5	18927.4	31.00	54.00	12905.0	495.65	2.29	4822.07	13.80	28.40	44.20	881.57
Shipyard	30.5	17765.2	31.00	54.00	11518.0	526.63	2.26	4376.96	13.10	28.40	43.80	916.48
Shipyard	31.5	18097.2	32.00	55.00	11216.5	495.65	2.35	4451.14	13.50	29.20	43.00	925.21
Shipyard	32.5	17350.1	30.00	53.00	10131.0	410.46	2.52	4228.59	13.20	29.50	44.20	907.75
Shipyard	33.5	16436.9	29.00	50.00	9467.7	364.00	2.80	3857.66	12.40	27.50	44.90	1003.77
Shipyard	34.5	16353.9	29.00	50.00	9407.4	340.76	2.73	3857.66	12.60	27.60	44.40	964.49
Shipyard	35.5	17101.0	29.00	52.00	10010.4	333.02	2.86	4154.40	12.70	28.00	42.90	942.67
Shipyard	36.5	17599.1	30.00	53.00	10251.6	340.76	2.86	4228.59	13.00	28.50	43.80	964.49
Shipyard	37.5	18097.2	31.00	55.00	10613.4	340.76	3.04	4376.96	13.30	30.30	44.50	960.13
Shipyard	38.5	18761.3	32.00	57.00	11156.2	333.02	2.58	4525.33	13.80	30.40	43.90	872.84
Shipyard	39.5	18595.3	32.00	58.00	10914.9	309.78	2.67	4302.77	13.80	31.50	42.30	877.21

Table B.10 Total digestion metal concentrations Pb204-Sr for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively

Lake	Midpoint Depth (cm)	Pb204 ICP MS Total mg/kg	Pb206 ICP MS Total mg/kg	Pb207 ICP MS Total mg/kg	Pb208 ICP MS Total mg/kg	PbSUM ICP MS Total mg/kg	Pr ICP MS Total mg/kg	Rb ICP MS Total mg/kg	Sc ICP MS Total mg/kg	Sm ICP MS Total mg/kg	Sn ICP MS Total mg/kg	Sr ICP Total mg/kg
NE20	0.25	0.08	17.80	2.43	3.10	23.40	0.90	10.30	1.50	0.70	0.40	114.00
NE20	0.75	0.08	4.14	1.34	2.66	8.22	0.70	6.90	1.00	0.40	0.25	130.00
NE20	1.25	0.07	3.22	1.24	2.61	7.14	0.50	5.50	0.80	0.30	0.18	136.00
NE20	1.75	0.08	2.41	1.20	2.58	6.27	0.40	5.00	0.70	0.30	0.18	138.00
NE20	2.25	0.06	2.09	1.02	2.22	5.39	0.40	4.80	0.60	0.30	0.17	134.00
NE20	2.75	0.06	1.62	0.84	1.80	4.31	0.30	4.50	0.60	0.30	0.14	124.00
NE20	3.25	0.04	1.26	0.57	1.25	3.12	0.30	4.10	0.60	0.20	0.15	144.00
NE20	3.75	0.03	1.13	0.54	1.16	2.86	0.30	3.80	0.50	0.20	0.11	163.00
NE20	4.25	0.02	0.62	0.30	0.65	1.59	0.30	3.90	0.50	0.20	0.32	195.00
NE20	4.75	0.02	0.51	0.26	0.56	1.35	0.30	3.50	0.50	0.20	0.14	215.00
NE20	5.25	0.02	0.59	0.28	0.67	1.56	0.30	3.30	0.40	0.20	0.41	219.00
NE20	5.75	0.01	0.44	0.23	0.53	1.22	0.30	3.80	0.50	0.20	0.11	221.00
NE20	6.25	0.02	0.50	0.29	0.66	1.46	0.30	5.00	0.60	0.20	0.13	185.00
NE20	6.75	0.02	0.49	0.31	0.69	1.51	0.40	5.60	0.70	0.20	0.11	150.00
NE20	7.25	0.02	0.60	0.34	0.77	1.74	0.40	5.90	0.70	0.30	0.13	108.00
NE20	7.75	0.02	0.65	0.37	0.83	1.88	0.40	6.00	0.70	0.30	0.13	101.00
NE20	8.25	0.21	3.56	2.95	6.94	13.70	0.50	6.20	0.80	0.30	0.24	118.00
NE20	8.75	0.03	0.71	0.42	0.97	2.13	0.50	6.30	0.80	0.30	0.14	109.00
NE20	9.25	0.03	0.70	0.40	0.95	2.07	0.50	6.00	0.70	0.30	0.17	77.00
NE20	9.75	0.03	0.72	0.43	1.00	2.18	0.50	6.50	0.80	0.30	0.15	66.00
NE20	10.25	0.03	0.61	0.40	0.93	1.97	0.40	6.40	0.80	0.30	0.26	71.00
NE20	10.75	0.03	0.61	0.40	0.91	1.94	0.50	6.10	0.80	0.30	1.16	80.00
NE20	11.25	0.03	0.65	0.39	0.92	1.99	0.40	6.10	0.80	0.30	0.15	76.00
NE20	11.75	0.03	0.61	0.39	0.88	1.91	0.40	5.90	0.70	0.30	0.14	76.00
NE20	12.25	0.02	0.62	0.35	0.81	1.80	0.40	5.90	0.70	0.30	0.13	76.00
NE20	12.75	0.02	0.56	0.35	0.80	1.72	0.40	6.00	0.70	0.30	0.15	85.00

NE20	13.25	0.02	0.50	0.32	0.75	1.59	0.40	5.90	0.70	0.30	0.15	90.00
NE20	13.75	0.02	0.56	0.34	0.78	1.70	0.40	6.30	0.80	0.30	0.12	90.00
NE20	14.25	0.04	0.81	0.58	1.34	2.76	0.50	6.50	0.80	0.40	0.30	85.00
NE20	14.75	0.03	0.63	0.37	0.86	1.89	0.50	6.80	0.80	0.30	0.17	92.00
NE20	15.25	0.03	0.56	0.36	0.91	1.86	0.50	7.00	0.80	0.30	0.15	88.00
NE20	15.75	0.03	0.57	0.37	0.87	1.83	0.50	7.00	0.90	0.40	2.37	91.00
NE20	16.25	0.02	0.52	0.35	0.83	1.72	0.50	6.90	0.80	0.40	0.17	90.00
NE20	16.75	0.02	0.51	0.35	0.82	1.69	0.50	6.90	0.80	0.30	0.16	91.00
NE20	17.25	0.03	0.50	0.38	0.87	1.77	0.50	6.80	0.80	0.30	0.27	92.00
NE20	17.75	0.02	0.50	0.37	0.89	1.79	0.50	6.70	0.80	0.30	0.30	92.00
NE20	18.25	0.04	0.81	0.64	1.47	2.97	0.50	6.70	0.80	0.30	0.17	100.00
NE20	18.75	0.03	0.60	0.41	0.97	2.00	0.50	6.80	0.90	0.40	0.24	105.00
NE20	19.25	0.03	0.53	0.38	0.89	1.82	0.50	6.60	0.80	0.40	0.30	108.00
NE20	19.75	0.02	0.50	0.37	0.87	1.76	0.50	6.70	0.80	0.40	0.49	111.00
NE20	20.5	0.02	0.48	0.36	0.85	1.71	0.50	6.90	0.80	0.40	0.24	116.00
NE20	21.5	0.02	0.43	0.32	0.79	1.57	0.50	6.50	0.80	0.30	0.17	117.00
NE20	22.5	0.02	0.45	0.36	0.85	1.68	0.50	6.70	0.80	0.30	0.14	126.00
NE20	23.5	0.02	0.40	0.31	0.76	1.48	0.50	6.30	0.80	0.30	0.12	140.00
NE20	24.5	0.03	0.41	0.33	0.79	1.56	0.50	6.60	0.90	0.40	0.11	151.00
NE20	25.5	0.02	0.41	0.32	0.77	1.53	0.40	6.70	0.90	0.30	0.15	142.00
NE20	26.5	0.02	0.45	0.34	0.81	1.62	0.50	7.30	0.90	0.30	0.13	153.00
NE20	27.5	0.02	0.42	0.33	0.81	1.58	0.50	7.10	0.90	0.30	0.40	178.00
NE20	28.5	0.02	0.38	0.29	0.71	1.40	0.40	5.90	0.80	0.30	0.14	192.00
NE20	29.5	0.02	0.36	0.28	0.67	1.33	0.40	5.50	0.70	0.30	0.32	174.00
NE20	30.5	0.02	0.32	0.25	0.56	1.14	0.30	4.40	0.60	0.20	0.10	169.00
NE20	31.5	0.02	0.29	0.23	0.53	1.07	0.30	4.10	0.60	0.20	0.11	184.00
NE20	32.5	0.02	0.31	0.24	0.55	1.11	0.30	4.10	0.60	0.20	0.10	178.00
NE20	33.5	0.01	0.27	0.21	0.50	0.98	0.30	4.20	0.60	0.20	0.10	193.00
NE20	34.5	0.01	0.27	0.22	0.53	1.04	0.30	4.10	0.50	0.20	0.11	193.00
NE20	35.5	0.02	0.33	0.26	0.61	1.21	0.40	5.70	0.70	0.30	0.11	171.00
NE20	36.5	0.03	0.48	0.37	0.89	1.76	0.50	7.00	0.80	0.40	0.13	152.00
NE20	37.5	0.02	0.32	0.25	0.61	1.19	0.40	5.10	0.70	0.30	0.21	159.00

NE20	38.5	0.01	0.27	0.20	0.48	0.96	0.30	3.90	0.50	0.20	0.10	169.00
NE20	39.5	0.01	0.26	0.20	0.49	0.96	0.30	4.10	0.50	0.20	0.08	204.00
NE20	40.5	0.01	0.24	0.18	0.44	0.88	0.20	3.60	0.50	0.20	0.07	208.00
NE20	41.5	0.01	0.19	0.15	0.35	0.70	0.20	3.00	0.40	0.10	0.07	224.00
NE20	42.5	0.01	0.13	0.10	0.24	0.46	0.10	1.90	0.30	0.10	0.07	265.00
NE20	43.5	0.01	0.09	0.07	0.16	0.33	0.10	1.60	0.30	<0.1	0.05	265.00
Isadore's	0.25	0.22	3.78	3.21	7.96	15.20	6.30	77.60	10.80	4.20	1.50	137.00
Isadore's	0.75	0.22	3.92	3.28	8.24	15.60	6.70	81.80	11.70	4.40	1.52	144.00
Isadore's	1.25	0.22	3.91	3.26	8.10	15.50	6.50	81.50	11.60	4.30	1.47	145.00
Isadore's	1.75	0.22	4.00	3.29	8.29	15.80	6.70	83.50	12.00	4.40	1.51	147.00
Isadore's	2.25	0.22	3.74	3.10	7.80	14.90	6.20	75.80	10.70	4.10	1.46	147.00
Isadore's	2.75	0.21	3.71	3.07	7.71	14.70	6.10	74.30	10.50	4.00	1.43	145.00
Isadore's	3.25	0.22	3.72	3.13	7.74	14.80	6.10	74.40	10.60	4.10	1.48	145.00
Isadore's	3.75	0.23	3.92	3.32	8.22	15.70	6.80	85.90	12.20	4.50	1.55	146.00
Isadore's	4.25	0.22	3.90	3.28	8.23	15.60	6.90	85.40	12.20	4.50	1.58	151.00
Isadore's	4.75	0.23	3.94	3.31	8.36	15.80	6.80	87.30	12.40	4.50	1.62	149.00
Isadore's	5.25	0.23	4.05	3.39	8.46	16.10	7.10	88.10	12.60	4.90	1.62	149.00
Isadore's	5.75	0.23	3.92	3.35	8.29	15.80	7.10	87.80	12.40	4.70	1.58	155.00
Isadore's	6.25	0.21	3.80	3.22	7.96	15.20	6.90	84.50	11.80	4.60	1.54	152.00
Isadore's	6.75	0.23	3.91	3.28	8.25	15.70	7.20	87.50	12.40	4.70	1.60	157.00
Isadore's	7.25	0.23	3.92	3.27	8.06	15.50	7.10	85.50	12.30	4.70	1.57	160.00
Isadore's	7.75	0.23	3.88	3.26	8.16	15.50	7.10	86.30	12.30	4.80	1.55	160.00
Isadore's	8.25	0.23	3.91	3.29	8.26	15.70	7.20	85.60	12.40	4.80	1.51	158.00
Isadore's	8.75	0.23	3.97	3.31	8.33	15.80	7.20	87.80	12.70	4.80	1.60	158.00
Isadore's	9.25	0.22	3.83	3.27	8.16	15.50	7.00	84.00	12.20	4.70	1.57	158.00
Isadore's	9.75	0.22	3.90	3.25	8.19	15.60	7.00	86.80	12.50	4.50	1.56	163.00
Isadore's	10.25	0.22	3.92	3.30	8.31	15.80	7.20	86.20	12.30	4.80	1.62	165.00
Isadore's	10.75	0.22	3.89	3.31	8.28	15.70	7.00	83.80	12.00	4.70	1.53	170.00
Isadore's	11.25	0.21	3.56	2.96	7.42	14.10	6.10	76.20	10.60	4.10	1.38	189.00
Isadore's	11.75	0.13	2.38	1.97	4.96	9.44	3.80	49.60	6.70	2.50	0.86	250.00
Isadore's	12.25	0.13	2.16	1.80	4.47	8.56	3.40	42.60	5.40	2.20	1.22	266.00
Isadore's	12.75	0.13	2.30	1.96	4.86	9.25	3.50	46.80	5.90	2.30	0.84	255.00

Isadore's	13.25	0.15	2.63	2.22	5.47	10.50	3.90	53.10	6.70	2.60	0.93	232.00
Isadore's	13.75	0.17	2.76	2.34	5.86	11.10	4.20	55.60	7.00	2.80	0.97	212.00
Isadore's	14.25	0.18	3.06	2.63	6.58	12.40	4.90	63.50	8.10	3.20	1.12	203.00
Isadore's	14.75	0.23	3.94	3.30	8.30	15.80	6.40	86.80	11.70	4.20	1.60	179.00
Isadore's	15.25	0.23	3.98	3.31	8.41	15.90	6.90	92.50	12.60	4.60	1.60	164.00
Isadore's	15.75	0.24	4.12	3.46	8.72	16.50	6.90	88.70	12.50	4.60	1.62	163.00
Isadore's	16.25	0.24	4.22	3.55	8.91	16.90	6.80	88.20	12.30	4.60	1.61	173.00
Isadore's	16.75	0.24	3.92	3.36	8.34	15.90	6.50	83.70	11.70	4.30	1.51	171.00
Isadore's	17.25	0.24	4.18	3.48	8.70	16.60	6.90	88.80	12.20	4.60	1.58	177.00
Isadore's	17.75	0.25	4.23	3.59	9.04	17.10	7.50	95.10	13.20	4.80	1.74	159.00
Isadore's	18.25	0.23	4.03	3.43	8.62	16.30	7.30	88.10	12.30	4.60	1.58	165.00
Isadore's	18.75	0.23	4.00	3.38	8.49	16.10	7.20	88.00	12.30	4.80	1.52	165.00
Isadore's	19.25	0.24	4.03	3.38	8.48	16.10	7.00	87.50	12.20	4.60	1.51	159.00
Isadore's	19.75	0.23	4.06	3.42	8.52	16.20	6.70	87.40	12.30	4.40	1.60	174.00
Isadore's	20.5	0.26	4.80	3.93	9.72	18.70	7.60	99.30	14.40	5.20	1.81	227.00
Isadore's	21.5	0.30	5.23	4.36	10.80	20.60	8.00	106.00	15.40	5.70	1.91	185.00
Isadore's	22.5	0.27	4.78	3.97	9.81	18.80	8.10	102.00	14.60	5.60	1.89	172.00
Isadore's	23.5	0.27	4.82	4.01	9.98	19.10	7.80	97.90	14.00	5.40	1.77	163.00
Isadore's	24.5	0.26	4.64	3.89	9.64	18.40	8.00	101.00	14.20	5.60	1.76	176.00
Isadore's	25.5	0.28	4.91	4.12	10.20	19.50	8.20	104.00	14.70	5.60	1.86	168.00
Isadore's	26.5	0.26	4.64	3.83	9.46	18.20	8.20	103.00	14.60	5.70	1.85	174.00
Isadore's	27.5	0.25	4.45	3.68	9.12	17.50	7.80	98.20	14.00	5.60	1.81	172.00
Isadore's	28.5	0.26	4.52	3.73	9.36	17.90	7.60	98.70	14.10	5.20	1.80	153.00
Isadore's	29.5	0.25	4.43	3.65	8.98	17.30	7.40	93.00	13.30	5.20	1.64	165.00
Isadore's	30.5	0.20	3.70	3.04	7.57	14.50	6.10	76.60	11.10	4.30	1.36	171.00
Isadore's	31.5	0.23	4.09	3.40	8.29	16.00	7.30	87.40	12.50	5.10	1.59	173.00
Isadore's	32.5	0.22	3.82	3.15	7.84	15.00	6.90	81.50	11.50	5.00	1.44	181.00
Isadore's	33.5	0.15	2.62	2.17	5.38	10.30	4.70	56.50	8.10	3.20	1.01	327.00
Isadore's	34.5	0.23	4.12	3.44	8.48	16.30	7.40	95.00	13.40	5.20	1.76	171.00
Isadore's	35.5	0.25	4.52	3.73	9.24	17.70	8.10	108.00	15.30	5.50	2.01	152.00
Isadore's	36.5	0.23	4.23	3.47	8.48	16.40	7.50	96.40	13.60	5.20	1.72	151.00
Isadore's	37.5	0.23	4.25	3.48	8.63	16.60	7.60	97.50	13.80	5.20	1.79	154.00

Isadore's	38.5	0.26	4.59	3.80	9.45	18.10	8.50	104.00	14.90	6.00	2.86	149.00
Isadore's	39.5	0.28	5.06	4.20	10.20	19.80	9.20	113.00	16.30	6.40	2.23	145.00
Shipyard	0.25	0.20	3.29	2.84	7.03	13.40	4.40	57.40	7.40	2.80	1.04	238.00
Shipyard	0.75	0.17	2.88	2.45	6.01	11.50	4.40	58.20	7.50	2.80	1.09	277.00
Shipyard	1.25	0.16	2.91	2.40	6.01	11.50	4.60	60.00	7.60	3.10	1.10	274.00
Shipyard	1.75	0.16	2.85	2.32	5.73	11.00	4.60	58.30	7.30	3.00	1.10	273.00
Shipyard	2.25	0.16	2.85	2.40	5.99	11.40	4.80	60.80	7.70	3.10	1.12	265.00
Shipyard	2.75	0.17	3.02	2.47	6.22	11.90	4.90	63.10	7.90	3.10	1.20	238.00
Shipyard	3.25	0.18	3.02	2.56	6.39	12.20	4.90	64.30	8.00	3.20	1.25	225.00
Shipyard	3.75	0.17	2.98	2.47	6.23	11.80	4.90	63.90	7.80	3.20	1.16	210.00
Shipyard	4.25	0.16	2.80	2.36	5.91	11.20	4.70	58.00	7.10	3.00	1.31	195.00
Shipyard	4.75	0.18	3.11	2.66	6.59	12.50	4.80	59.50	7.30	3.20	1.15	200.00
Shipyard	5.25	0.15	2.58	2.18	5.43	10.30	4.50	53.80	6.50	3.00	1.05	200.00
Shipyard	5.75	0.16	2.81	2.29	5.72	11.00	4.40	55.90	6.80	3.00	1.08	192.00
Shipyard	6.25	0.17	2.97	2.50	6.19	11.80	4.90	62.40	7.80	3.30	1.49	176.00
Shipyard	6.75	0.19	3.14	2.62	6.48	12.40	5.00	67.20	8.60	3.20	1.61	167.00
Shipyard	7.25	0.20	3.39	2.88	7.13	13.60	5.50	72.20	9.50	3.60	1.35	156.00
Shipyard	7.75	0.18	3.16	2.66	6.66	12.70	5.10	69.30	8.90	3.20	1.47	142.00
Shipyard	8.25	0.20	3.46	2.92	7.30	13.90	5.60	76.90	9.90	3.50	1.40	185.00
Shipyard	8.75	0.20	3.53	2.91	7.27	13.90	5.60	76.40	9.90	3.50	1.32	207.00
Shipyard	9.25	0.22	3.74	3.16	7.88	15.00	6.10	85.50	11.00	3.90	1.51	217.00
Shipyard	9.75	0.23	4.05	3.36	8.43	16.10	6.60	90.30	11.90	4.10	1.56	207.00
Shipyard	10.25	0.24	4.11	3.51	8.85	16.70	6.90	93.20	12.30	4.30	1.67	193.00
Shipyard	10.75	0.25	4.24	3.64	9.09	17.20	7.00	96.60	12.60	4.40	1.75	192.00
Shipyard	11.25	0.25	4.22	3.55	8.84	16.90	7.10	92.60	12.40	4.60	1.76	203.00
Shipyard	11.75	0.24	4.10	3.47	8.65	16.50	6.90	92.10	12.10	4.50	1.64	222.00
Shipyard	12.25	0.25	4.24	3.59	9.07	17.10	7.10	95.90	12.60	4.50	1.73	228.00
Shipyard	12.75	0.24	4.31	3.62	9.04	17.20	7.10	97.00	12.70	4.40	1.74	189.00
Shipyard	13.25	0.25	4.36	3.69	9.30	17.60	7.10	97.60	13.00	4.60	1.78	173.00
Shipyard	13.75	0.24	4.20	3.57	8.88	16.90	7.20	91.80	12.40	4.70	1.69	198.00
Shipyard	14.25	0.25	4.29	3.68	9.15	17.40	7.50	94.70	12.80	4.90	1.69	184.00
Shipyard	14.75	0.25	4.48	3.77	9.42	17.90	7.50	101.00	13.80	4.80	1.86	156.00

Shipyard	15.25	0.26	4.56	3.89	9.65	18.40	7.80	103.00	14.30	5.00	1.84	152.00
Shipyard	15.75	0.26	4.51	3.83	9.46	18.00	7.70	99.20	14.00	5.10	1.84	148.00
Shipyard	16.25	0.27	4.56	3.79	9.54	18.20	7.80	103.00	14.10	5.00	1.93	151.00
Shipyard	16.75	0.25	4.24	3.69	9.14	17.30	7.60	102.00	13.80	4.90	1.84	148.00
Shipyard	17.25	0.22	3.89	3.28	8.23	15.60	6.80	92.60	12.60	4.30	1.67	146.00
Shipyard	17.75	0.22	3.76	3.22	8.07	15.30	6.60	91.00	12.40	4.10	1.57	145.00
Shipyard	18.25	0.22	3.84	3.28	8.20	15.50	6.80	94.20	12.70	4.30	1.62	141.00
Shipyard	18.75	0.23	3.82	3.25	8.09	15.40	6.70	92.60	12.50	4.20	1.69	141.00
Shipyard	19.25	0.23	3.75	3.20	8.03	15.20	6.70	88.70	12.10	4.20	1.60	144.00
Shipyard	19.75	0.23	3.77	3.17	7.81	15.00	6.50	87.00	12.00	4.30	1.55	146.00
Shipyard	20.5	0.26	4.56	3.78	9.30	17.90	8.20	108.00	15.30	5.80	1.91	151.00
Shipyard	21.5	0.26	4.61	3.77	9.34	18.00	8.40	112.00	15.40	5.70	2.00	141.00
Shipyard	22.5	0.26	4.68	3.90	9.60	18.40	8.40	113.00	15.90	5.70	2.03	140.00
Shipyard	23.5	0.25	4.32	3.54	8.84	17.00	8.00	105.00	14.70	5.60	1.93	149.00
Shipyard	24.5	0.26	4.56	3.81	9.33	18.00	7.50	92.10	13.70	5.40	1.68	133.00
Shipyard	25.5	0.24	4.27	3.58	8.89	17.00	7.70	104.00	14.80	5.20	1.89	153.00
Shipyard	26.5	0.17	3.07	2.50	6.24	12.00	5.50	72.20	10.00	3.80	1.33	237.00
Shipyard	27.5	0.23	4.06	3.39	8.49	16.20	7.10	97.70	13.50	5.00	1.70	200.00
Shipyard	28.5	0.25	4.38	3.56	8.86	17.00	7.60	102.00	14.40	5.30	1.85	165.00
Shipyard	29.5	0.24	4.26	3.55	8.74	16.80	7.80	102.00	14.30	5.30	1.82	163.00
Shipyard	30.5	0.24	4.24	3.50	8.58	16.60	7.80	98.10	13.90	5.40	1.71	149.00
Shipyard	31.5	0.23	4.24	3.48	8.64	16.60	7.80	102.00	14.50	5.40	1.85	138.00
Shipyard	32.5	0.24	4.21	3.46	8.68	16.60	7.90	102.00	14.40	5.40	1.82	121.00
Shipyard	33.5	0.24	4.08	3.38	8.43	16.10	7.40	96.90	13.80	5.20	1.70	116.00
Shipyard	34.5	0.24	4.19	3.49	8.54	16.50	7.50	98.90	13.80	5.20	1.73	116.00
Shipyard	35.5	0.23	4.11	3.38	8.42	16.10	7.60	98.90	14.00	5.20	1.81	118.00
Shipyard	36.5	0.30	5.15	4.29	10.50	20.20	7.70	99.80	14.20	5.50	1.78	122.00
Shipyard	37.5	0.39	6.62	5.54	13.60	26.20	8.10	94.60	14.40	5.70	1.90	125.00
Shipyard	38.5	0.30	5.02	4.18	10.20	19.70	8.30	97.00	14.90	5.80	1.94	128.00
Shipyard	39.5	0.30	5.16	4.26	10.40	20.20	8.50	96.50	14.80	6.00	2.00	123.00

Table B.11 Total digestion metal concentrations Ta-Zr for cores P-NE20, I1, and S1 from NE20, Isadore's Lake, and Shipyard Lake, respectively.

Lake	Midpoint Depth (cm)	Ta ICP MS Total mg/kg	Tb ICP MS Total mg/kg	Th ICP MS Total mg/kg	Ti Total mg/kg	U ICP MS Total mg/kg	V ICP MS Total mg/kg	W ICP MS Total mg/kg	Y ICP MS Total mg/kg	Yb ICP MS Total mg/kg	Zn ICP MS Total mg/kg	Zr ICP Total mg/kg
NE20	0.25	0.16	0.13	1.91	437.52	127.00	71.20	2.30	3.80	0.33	49.00	22.00
NE20	0.75	0.07	0.05	0.97	275.70	8.85	61.20	1.60	1.90	0.19	49.00	13.00
NE20	1.25	0.05	0.04	0.74	209.77	5.22	54.10	1.10	1.50	0.15	51.00	10.00
NE20	1.75	0.05	0.04	0.64	167.82	3.06	34.20	1.00	1.40	0.12	57.00	8.00
NE20	2.25	0.04	0.04	0.59	137.85	2.65	16.00	0.90	1.20	0.10	60.00	7.00
NE20	2.75	0.04	0.03	0.55	125.86	1.80	10.70	0.70	1.20	0.12	64.00	7.00
NE20	3.25	0.03	0.03	0.52	101.89	1.94	8.30	0.70	1.10	0.10	63.00	6.00
NE20	3.75	0.03	0.03	0.45	83.91	1.56	7.40	0.50	1.00	0.09	54.00	5.00
NE20	4.25	0.02	0.03	0.43	71.92	1.00	5.70	0.50	1.00	0.09	46.00	5.00
NE20	4.75	0.03	0.02	0.41	53.94	0.90	5.40	0.50	0.90	0.08	40.00	4.00
NE20	5.25	0.02	0.02	0.38	41.95	0.82	4.70	0.50	0.80	0.08	34.00	3.00
NE20	5.75	0.03	0.02	0.38	65.93	0.74	5.50	0.50	0.90	0.07	37.00	4.00
NE20	6.25	0.03	0.03	0.48	107.88	0.82	5.70	0.50	1.30	0.12	45.00	6.00
NE20	6.75	0.04	0.03	0.52	143.84	0.84	5.90	0.50	1.20	0.11	57.00	7.00
NE20	7.25	0.04	0.03	0.60	173.81	1.40	6.50	0.60	1.20	0.12	60.00	8.00
NE20	7.75	0.04	0.04	0.71	179.80	1.01	6.20	0.60	1.30	0.13	74.00	8.00
NE20	8.25	0.05	0.04	0.67	191.79	1.01	7.20	0.70	1.40	0.14	80.00	8.00
NE20	8.75	0.07	0.05	0.70	191.79	1.26	7.50	0.70	1.40	0.14	82.00	8.00
NE20	9.25	0.05	0.04	0.71	197.78	1.42	6.60	0.80	1.40	0.15	80.00	9.00
NE20	9.75	0.05	0.04	0.83	209.77	1.13	6.30	0.60	1.40	0.15	74.00	10.00
NE20	10.25	0.05	0.04	0.69	203.78	0.70	6.60	0.80	1.40	0.14	79.00	9.00
NE20	10.75	0.05	0.04	0.72	203.78	0.76	6.80	0.80	1.30	0.14	81.00	9.00
NE20	11.25	0.05	0.04	0.70	209.77	1.11	6.60	0.80	1.30	0.14	83.00	8.00
NE20	11.75	0.05	0.04	0.64	197.78	0.74	6.60	0.80	1.30	0.14	82.00	8.00
NE20	12.25	0.05	0.04	0.63	185.80	1.02	6.30	0.70	1.30	0.13	87.00	7.00
NE20	12.75	0.04	0.04	0.65	185.80	0.66	6.30	0.70	1.30	0.13	94.00	7.00

NE20	13.25	0.05	0.04	0.63	179.80	0.55	5.60	0.70	1.30	0.13	88.00	7.00
NE20	13.75	0.05	0.04	0.66	203.78	0.56	5.90	0.60	1.40	0.16	87.00	8.00
NE20	14.25	0.05	0.04	0.71	203.78	1.04	5.70	0.70	1.40	0.14	92.00	9.00
NE20	14.75	0.06	0.04	0.73	209.77	0.60	6.60	0.60	1.50	0.14	97.00	10.00
NE20	15.25	0.05	0.04	0.72	215.76	0.64	6.20	0.60	1.50	0.15	101.00	9.00
NE20	15.75	0.05	0.04	0.75	209.77	0.68	6.10	0.60	1.50	0.15	102.00	8.00
NE20	16.25	0.06	0.04	0.75	203.78	0.49	5.80	0.60	1.50	0.14	102.00	9.00
NE20	16.75	0.05	0.04	0.73	209.77	0.56	6.40	0.60	1.50	0.16	103.00	9.00
NE20	17.25	0.04	0.04	0.72	209.77	0.51	6.20	0.60	1.60	0.15	104.00	9.00
NE20	17.75	0.05	0.04	0.70	197.78	0.46	5.90	0.50	1.40	0.14	100.00	9.00
NE20	18.25	0.05	0.04	0.71	203.78	0.61	6.30	0.50	1.50	0.15	100.00	9.00
NE20	18.75	0.06	0.04	0.85	209.77	0.89	6.80	0.60	1.50	0.15	100.00	10.00
NE20	19.25	0.05	0.04	0.74	203.78	0.59	6.20	0.40	1.50	0.15	98.00	9.00
NE20	19.75	0.05	0.04	0.73	203.78	0.56	6.20	0.50	1.50	0.15	100.00	8.00
NE20	20.5	0.05	0.04	0.71	203.78	0.48	6.50	0.50	1.50	0.15	99.00	9.00
NE20	21.5	0.04	0.04	0.67	197.78	0.47	6.60	0.50	1.50	0.14	91.00	9.00
NE20	22.5	0.05	0.04	0.72	191.79	0.51	6.10	0.40	1.50	0.14	103.00	9.00
NE20	23.5	0.04	0.04	0.71	179.80	0.38	6.50	0.40	1.40	0.13	103.00	8.00
NE20	24.5	0.05	0.04	0.80	191.79	0.40	6.60	0.60	1.50	0.14	112.00	10.00
NE20	25.5	0.04	0.04	0.70	191.79	0.38	6.80	0.40	1.50	0.15	114.00	9.00
NE20	26.5	0.04	0.04	0.75	197.78	0.38	6.90	0.50	1.50	0.15	110.00	9.00
NE20	27.5	0.05	0.04	0.71	179.80	0.43	6.90	0.40	1.40	0.14	105.00	8.00
NE20	28.5	0.04	0.04	0.56	143.84	0.39	5.50	0.30	1.30	0.11	93.00	7.00
NE20	29.5	0.04	0.03	0.56	143.84	0.34	5.30	0.30	1.20	0.11	96.00	7.00
NE20	30.5	0.03	0.03	0.49	107.88	0.38	5.00	0.30	1.10	0.10	85.00	6.00
NE20	31.5	0.03	0.02	0.46	89.90	0.38	4.00	0.30	1.00	0.08	80.00	5.00
NE20	32.5	0.03	0.03	0.44	95.89	0.34	4.80	0.30	1.10	0.10	74.00	5.00
NE20	33.5	0.03	0.02	0.41	83.91	0.34	4.70	0.30	1.00	0.09	70.00	5.00
NE20	34.5	0.03	0.02	0.40	83.91	0.26	4.10	0.30	1.00	0.09	59.00	4.00
NE20	35.5	0.04	0.03	0.54	149.84	0.35	5.90	0.30	1.30	0.11	71.00	6.00
NE20	36.5	0.05	0.04	0.93	233.74	0.67	6.70	0.40	1.50	0.15	78.00	10.00
NE20	37.5	0.04	0.03	0.58	131.86	0.43	4.60	0.30	1.20	0.12	75.00	7.00

NE20	38.5	0.03	0.03	0.47	83.91	0.47	4.40	0.30	1.00	0.09	65.00	4.00
NE20	39.5	0.03	0.02	0.42	83.91	0.29	4.40	0.30	0.90	0.09	65.00	4.00
NE20	40.5	0.02	0.02	0.36	53.94	0.31	3.80	0.30	0.80	0.08	62.00	4.00
NE20	41.5	0.02	<0.02	0.29	23.97	0.28	3.60	0.20	0.70	0.07	53.00	2.00
NE20	42.5	<0.02	<0.02	0.20	5.99	0.19	2.40	0.20	0.50	0.04	39.00	<1
NE20	43.5	<0.02	<0.02	0.14	5.99	0.18	1.70	0.20	0.40	0.03	31.00	<1
Isadore's	0.25	0.64	0.52	8.83	3356.32	3.24	116.00	2.20	16.40	1.92	96.00	106.00
Isadore's	0.75	0.71	0.56	9.79	3584.07	3.16	123.00	2.20	17.50	2.07	96.00	112.00
Isadore's	1.25	0.72	0.56	9.34	3632.02	4.06	124.00	2.10	17.30	2.05	97.00	111.00
Isadore's	1.75	0.72	0.57	9.67	3721.92	3.83	128.00	2.10	17.60	2.11	99.00	115.00
Isadore's	2.25	0.72	0.53	9.02	3763.87	3.00	129.00	1.40	17.20	1.87	100.00	118.00
Isadore's	2.75	0.70	0.51	8.90	3709.93	2.91	130.00	1.40	16.80	1.82	95.00	113.00
Isadore's	3.25	0.74	0.52	8.89	3715.93	2.96	130.00	1.40	16.80	1.81	99.00	116.00
Isadore's	3.75	0.74	0.58	9.68	3769.87	3.13	129.00	1.80	18.40	2.10	100.00	115.00
Isadore's	4.25	0.74	0.58	9.83	3871.76	3.00	134.00	1.70	18.20	2.10	101.00	116.00
Isadore's	4.75	0.76	0.60	9.80	3895.73	3.15	134.00	1.70	18.30	2.21	103.00	120.00
Isadore's	5.25	0.80	0.60	10.10	3991.62	3.71	133.00	1.60	18.90	2.25	103.00	124.00
Isadore's	5.75	0.79	0.60	10.00	4099.51	3.10	136.00	1.50	18.80	2.23	102.00	139.00
Isadore's	6.25	0.76	0.63	9.77	4039.57	3.22	132.00	1.40	18.40	2.17	98.00	125.00
Isadore's	6.75	0.78	0.61	9.84	4087.52	3.07	134.00	1.40	19.20	2.20	102.00	125.00
Isadore's	7.25	0.80	0.60	9.90	4165.43	3.79	133.00	1.40	19.20	2.24	102.00	128.00
Isadore's	7.75	0.79	0.60	10.00	4207.39	3.10	135.00	1.40	19.30	2.26	102.00	131.00
Isadore's	8.25	0.80	0.62	10.10	4147.45	3.14	134.00	1.50	19.40	2.26	103.00	129.00
Isadore's	8.75	0.80	0.62	10.10	4171.43	3.14	134.00	1.40	19.60	2.24	105.00	128.00
Isadore's	9.25	0.76	0.61	9.93	4117.49	3.05	134.00	1.40	18.90	2.26	102.00	126.00
Isadore's	9.75	0.80	0.58	9.80	4153.45	3.12	134.00	1.40	19.10	2.22	103.00	122.00
Isadore's	10.25	0.79	0.62	10.30	4033.58	3.25	128.00	1.40	19.40	2.25	104.00	124.00
Isadore's	10.75	0.79	0.59	9.79	4003.61	3.23	128.00	1.40	18.80	2.15	101.00	123.00
Isadore's	11.25	0.71	0.51	8.78	3500.16	3.09	117.00	1.30	16.70	1.92	90.00	108.00
Isadore's	11.75	0.41	0.33	5.36	2169.62	1.92	84.20	0.80	11.00	1.24	58.00	71.00
Isadore's	12.25	0.36	0.29	4.63	1810.02	1.85	75.90	0.70	9.10	1.03	49.00	62.00
Isadore's	12.75	0.38	0.29	5.04	1929.88	1.81	86.30	0.80	9.60	1.09	53.00	62.00

Isadore's	13.25	0.42	0.32	5.65	2145.65	1.93	101.00	0.80	10.60	1.23	60.00	69.00
Isadore's	13.75	0.45	0.35	6.03	2319.46	1.94	111.00	0.80	11.70	1.31	63.00	74.00
Isadore's	14.25	0.50	0.42	6.78	2715.02	2.12	129.00	1.00	13.50	1.48	73.00	85.00
Isadore's	14.75	0.70	0.55	8.84	3655.99	2.72	153.00	1.30	17.80	2.01	97.00	107.00
Isadore's	15.25	0.78	0.59	9.62	4165.43	2.88	154.00	1.40	18.70	2.09	107.00	117.00
Isadore's	15.75	0.79	0.58	9.92	3889.74	2.99	150.00	1.40	18.60	2.15	102.00	116.00
Isadore's	16.25	0.77	0.56	9.82	3937.68	2.88	149.00	1.40	18.40	2.07	101.00	117.00
Isadore's	16.75	0.72	0.54	9.34	3745.89	2.71	136.00	1.30	17.70	1.99	97.00	110.00
Isadore's	17.25	0.77	0.58	9.90	3973.64	3.09	144.00	1.40	18.70	2.10	102.00	132.00
Isadore's	17.75	0.82	0.62	10.70	4171.43	3.15	150.00	1.50	19.60	2.24	107.00	120.00
Isadore's	18.25	0.79	0.61	10.10	4093.51	3.14	135.00	1.40	19.50	2.29	102.00	130.00
Isadore's	18.75	0.89	0.61	9.98	4027.58	3.25	132.00	1.60	19.90	2.21	102.00	130.00
Isadore's	19.25	0.79	0.58	10.00	3739.90	3.16	133.00	1.50	19.00	2.16	102.00	115.00
Isadore's	19.75	0.77	0.56	9.84	3679.97	3.18	136.00	1.40	18.00	2.01	102.00	110.00
Isadore's	20.5	0.79	0.60	11.30	3787.85	3.65	147.00	1.50	19.80	2.01	108.00	104.00
Isadore's	21.5	0.85	0.63	11.90	4069.54	3.66	150.00	1.60	21.10	2.15	115.00	109.00
Isadore's	22.5	0.83	0.65	11.60	4099.51	3.63	147.00	1.60	21.00	2.22	110.00	114.00
Isadore's	23.5	0.78	0.60	11.20	3811.82	3.49	142.00	1.50	20.40	2.06	108.00	105.00
Isadore's	24.5	0.83	0.64	11.50	4027.58	3.37	143.00	1.60	21.00	2.14	108.00	113.00
Isadore's	25.5	0.87	0.64	11.80	4165.43	3.54	142.00	1.70	21.20	2.20	112.00	113.00
Isadore's	26.5	0.85	0.66	11.70	4237.35	3.48	145.00	1.60	21.20	2.18	110.00	115.00
Isadore's	27.5	0.81	0.63	11.10	4003.61	3.18	142.00	1.50	20.70	2.12	108.00	111.00
Isadore's	28.5	0.77	0.60	10.90	3931.69	3.00	144.00	1.50	20.10	2.03	107.00	111.00
Isadore's	29.5	0.74	0.57	10.50	3721.92	3.05	135.00	1.40	19.20	2.00	102.00	108.00
Isadore's	30.5	0.61	0.48	8.64	3116.58	2.55	116.00	1.20	17.00	1.71	87.00	96.00
Isadore's	31.5	0.75	0.59	10.00	3793.84	2.91	131.00	1.40	19.40	2.06	98.00	117.00
Isadore's	32.5	0.82	0.55	9.41	3608.04	2.92	118.00	1.30	18.40	1.91	91.00	112.00
Isadore's	33.5	0.44	0.38	6.31	2271.51	1.98	84.40	0.80	13.30	1.28	61.00	69.00
Isadore's	34.5	0.78	0.60	10.30	3799.83	2.80	145.00	1.40	19.60	1.98	101.00	110.00
Isadore's	35.5	0.84	0.63	11.50	4111.49	3.08	150.00	1.50	20.80	2.14	108.00	116.00
Isadore's	36.5	0.77	0.60	10.50	3841.79	2.89	140.00	1.40	19.90	2.02	102.00	110.00
Isadore's	37.5	0.80	0.60	10.60	3883.74	3.07	148.00	1.50	20.30	2.09	106.00	111.00

Isadore's	38.5	0.84	0.67	11.60	4111.49	3.40	153.00	1.60	23.20	2.30	112.00	120.00
Isadore's	39.5	0.98	0.73	12.70	4728.82	4.36	160.00	1.80	24.90	2.49	124.00	134.00
Shipyard	0.25	0.48	0.37	6.24	2133.66	2.26	90.20	1.90	11.60	1.28	82.00	75.00
Shipyard	0.75	0.45	0.35	6.20	2229.56	2.08	94.60	1.80	11.60	1.27	67.00	75.00
Shipyard	1.25	0.48	0.38	6.42	2229.56	2.58	95.80	1.90	12.10	1.37	68.00	77.00
Shipyard	1.75	0.47	0.37	6.20	2265.52	2.85	96.40	1.80	11.80	1.32	65.00	81.00
Shipyard	2.25	0.50	0.38	6.47	2373.40	2.50	102.00	2.00	12.40	1.37	68.00	86.00
Shipyard	2.75	0.51	0.39	6.74	2427.34	2.80	104.00	1.90	12.80	1.42	72.00	89.00
Shipyard	3.25	0.52	0.40	6.76	2457.31	2.89	106.00	2.10	13.00	1.43	80.00	87.00
Shipyard	3.75	0.51	0.40	6.68	2421.35	2.56	106.00	1.80	13.00	1.43	70.00	84.00
Shipyard	4.25	0.49	0.39	6.24	2301.48	2.37	97.90	1.50	12.30	1.38	65.00	83.00
Shipyard	4.75	0.47	0.40	6.27	2283.50	2.34	101.00	1.40	12.70	1.40	67.00	83.00
Shipyard	5.25	0.44	0.36	5.83	2055.75	2.22	94.80	1.30	12.00	1.33	62.00	75.00
Shipyard	5.75	0.44	0.37	5.77	2115.68	3.12	99.30	1.20	12.10	1.29	75.00	73.00
Shipyard	6.25	0.49	0.42	6.41	2385.38	2.64	112.00	1.30	13.20	1.44	71.00	83.00
Shipyard	6.75	0.50	0.43	6.93	2505.25	2.78	118.00	1.20	13.50	1.50	77.00	81.00
Shipyard	7.25	0.54	0.46	7.37	2744.99	2.56	132.00	1.20	14.30	1.61	80.00	85.00
Shipyard	7.75	0.52	0.42	7.06	2553.20	2.58	129.00	1.20	13.90	1.51	77.00	82.00
Shipyard	8.25	0.58	0.47	7.72	2840.89	2.47	142.00	1.20	14.50	1.62	82.00	86.00
Shipyard	8.75	0.58	0.44	7.77	2906.81	3.14	150.00	1.10	14.30	1.56	84.00	90.00
Shipyard	9.25	0.65	0.49	8.62	3230.46	2.38	165.00	1.20	15.20	1.71	91.00	95.00
Shipyard	9.75	0.72	0.51	9.33	3422.25	2.64	172.00	1.30	16.50	2.03	97.00	100.00
Shipyard	10.25	0.75	0.54	9.70	3661.99	2.78	179.00	1.30	16.80	1.92	103.00	106.00
Shipyard	10.75	0.76	0.56	10.20	3829.80	2.92	184.00	1.40	17.80	2.04	105.00	109.00
Shipyard	11.25	0.75	0.56	9.88	3733.91	2.87	185.00	1.30	17.70	2.04	103.00	104.00
Shipyard	11.75	0.72	0.56	9.47	3638.01	2.84	184.00	1.30	18.00	2.00	101.00	108.00
Shipyard	12.25	0.76	0.57	9.88	3632.02	3.06	186.00	1.30	18.10	2.03	102.00	107.00
Shipyard	12.75	0.74	0.56	9.95	3650.00	2.94	192.00	1.40	17.90	2.01	102.00	103.00
Shipyard	13.25	0.77	0.57	10.20	3745.89	2.96	196.00	1.40	18.90	2.12	103.00	107.00
Shipyard	13.75	0.74	0.60	9.76	3536.12	2.95	177.00	1.30	19.30	2.13	98.00	107.00
Shipyard	14.25	0.79	0.62	10.40	3901.72	3.21	160.00	1.40	19.80	2.19	105.00	112.00
Shipyard	14.75	0.85	0.61	10.90	4285.30	3.38	156.00	1.50	19.10	2.16	112.00	117.00

Shipyard	15.25	0.87	0.64	11.20	4393.18	3.40	162.00	1.50	19.70	2.24	115.00	121.00
Shipyard	15.75	0.86	0.63	11.20	4219.37	3.26	156.00	1.50	20.20	2.38	114.00	122.00
Shipyard	16.25	0.86	0.63	11.20	4237.35	3.44	158.00	1.70	19.70	2.25	112.00	121.00
Shipyard	16.75	0.84	0.60	10.80	4183.41	3.57	157.00	1.50	19.50	2.19	110.00	115.00
Shipyard	17.25	0.74	0.54	9.92	4111.49	2.99	155.00	1.30	17.10	1.93	99.00	111.00
Shipyard	17.75	0.73	0.51	9.64	4135.47	2.95	155.00	1.20	16.30	1.89	98.00	112.00
Shipyard	18.25	0.75	0.53	10.00	4177.42	2.94	155.00	1.30	16.90	1.92	100.00	113.00
Shipyard	18.75	0.74	0.53	9.71	4123.48	2.90	153.00	1.20	16.80	1.89	98.00	111.00
Shipyard	19.25	0.72	0.54	9.47	3937.68	2.95	148.00	1.20	17.00	1.92	97.00	111.00
Shipyard	19.75	0.70	0.52	9.41	3937.68	2.88	149.00	1.20	16.60	1.91	95.00	109.00
Shipyard	20.5	0.82	0.64	11.30	4069.54	3.40	146.00	1.50	21.50	2.15	113.00	113.00
Shipyard	21.5	0.82	0.64	11.40	4117.49	3.40	152.00	1.50	21.30	2.17	116.00	114.00
Shipyard	22.5	0.84	0.63	11.60	4291.30	3.69	150.00	1.60	21.30	2.17	116.00	114.00
Shipyard	23.5	0.80	0.65	10.70	3955.66	3.85	141.00	1.50	21.30	2.12	110.00	108.00
Shipyard	24.5	0.68	0.65	10.10	3386.29	3.45	137.00	1.30	22.00	2.17	107.00	99.00
Shipyard	25.5	0.75	0.60	10.70	3596.06	3.20	138.00	1.40	20.50	2.02	109.00	99.00
Shipyard	26.5	0.51	0.43	7.29	2547.21	2.18	103.00	1.00	14.90	1.42	75.00	72.00
Shipyard	27.5	0.70	0.55	10.10	3578.08	3.08	140.00	1.30	19.00	1.91	104.00	97.00
Shipyard	28.5	0.79	0.60	10.80	3835.79	3.60	136.00	1.50	20.30	2.03	110.00	103.00
Shipyard	29.5	0.82	0.61	10.70	3943.68	3.24	147.00	1.50	20.60	2.02	110.00	107.00
Shipyard	30.5	0.74	0.60	10.50	3775.86	3.10	144.00	1.40	20.60	2.04	106.00	108.00
Shipyard	31.5	0.76	0.62	10.70	3907.72	3.15	141.00	1.40	21.10	2.09	109.00	112.00
Shipyard	32.5	0.77	0.63	10.70	3769.87	3.26	141.00	1.40	21.20	2.09	108.00	106.00
Shipyard	33.5	0.71	0.60	10.00	3542.12	3.39	133.00	1.40	20.20	1.99	108.00	99.00
Shipyard	34.5	0.73	0.61	10.10	3536.12	3.46	139.00	1.40	19.90	1.95	108.00	99.00
Shipyard	35.5	0.74	0.60	10.00	3715.93	3.39	143.00	1.40	20.00	1.97	107.00	103.00
Shipyard	36.5	0.74	0.61	10.20	3787.85	3.67	140.00	1.40	20.70	2.03	110.00	106.00
Shipyard	37.5	0.89	0.64	11.80	3943.68	4.52	143.00	1.60	21.20	2.19	110.00	112.00
Shipyard	38.5	0.90	0.66	12.20	4123.48	3.88	145.00	1.70	21.20	2.13	113.00	114.00
Shipyard	39.5	0.91	0.67	12.40	4141.46	4.11	144.00	1.60	21.40	2.27	107.00	115.00